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Volume 17 Number 12

BULLETIN
of the
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

DECEMBER 1933

VIOLA LIMESTONE, PRIMARILY OF ARBUCKLE AND WICHITA MOUNTAIN REGIONS, OKLAHOMA[1]

CHARLES E. DECKER[2]
Norman, Oklahoma

ABSTRACT

This paper deals briefly with the physical and faunal characteristics and correlation of the Viola limestone. Two tables and a number of measured sections are included showing the distribution of fossils and physical characteristics by zones. The 15 localities chosen for study are taken to be representative of the Viola in its numerous outcrops. Information is presented giving the evidence on which the Viola has been extended into the Atoka region where it has not been previously recognized, excepting that Taff indicated that the Stringtown shale, Talihina chert, and Jack Fork sandstone are equivalent in age to the Viola limestone.

INTRODUCTION

The Viola limestone[3] is one of the most distinctive lithologic units to be found among the Paleozoic formations of Oklahoma. Being a very resistant limestone, it contrasts strongly both in its outcrops and in its subsurface development with the soft, loose Sylvan shale above and the alternating limestones, shales, and sandstones of the Simpson group below. Also, being very fossiliferous, it is no less distinctive from a faunal standpoint, as very few of the numerous species in the Bromide of the Simpson enter it from below, and none of the species characteristic of the Viola is known to extend into the Sylvan shale above.

[1] Manuscript received, September 15, 1933.

[2] Professor of paleontology, University of Oklahoma.

[3] The Viola limestone was named for a former town of Viola about 4.5 miles southwest of Bromide. Only three old shacks mark the site of the old town near which the limestone crops out.

The purpose of the writer is to describe the characteristics of the Viola limestone, noting its distribution, topography, structure and drainage, lithologic character, thickness, age and correlations, stratigraphic relations, and the fauna in general together with a brief summary of the results of this study.

ACKNOWLEDGMENTS

Though the writer is responsible for field work and for the preparation of this paper, he is greatly indebted to Rudolf Ruedemann for his assistance in identifying, drawing, and describing the graptolites[4] listed. He is also indebted to the National Research Council for a grant of funds to assist in completing field work and to pay part of the expense of taking the extended collections to the New York State Museum at Albany for study, and to the New York State Museum for the many courtesies extended during the two months of study. Acknowledgment for assistance in the field is made to John Fitts, Rex McGehee, Norval Ballard, Ross Maxwell, Everett Orr, and J. O. Beach.

DISTRIBUTION

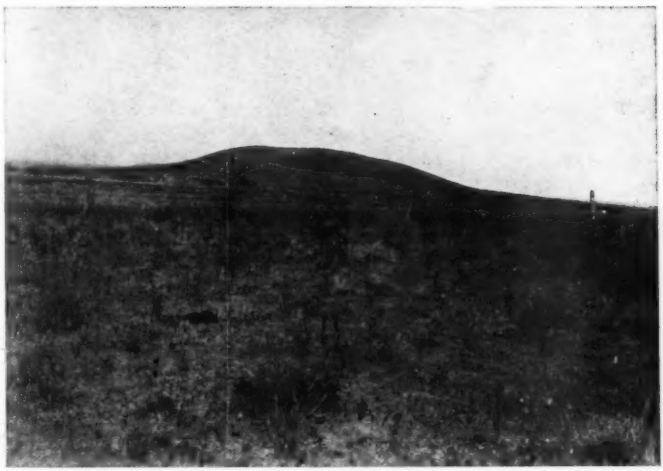
The Viola limestone has forty or more separate outcrops in the Arbuckle Mountains and the Wichita Mountains,[5] the Criner Hills, the Mansville anticline, and the Atoka region. Most of these outcrops are small, a square mile or less in area. The larger outcrops occur on the southwest side of the Arbuckle anticline in narrow strips from the vicinity of Pooleville almost to Ravia, two on either side of Washita River northwest of Dougherty, one east of Dougherty between Crusher and the Nebo Store, one at Lawrence southeast of Ada, and one extending from Franks southeasterly to Bromide. Other small exposures are scattered through the Arbuckle Mountains, Criner Hills, Mansville anticline, four small hills at the northwest edge of the Wichita Mountains southeast of Gotebo, and a narrow strip about 10 miles long east and northeast of Atoka. It has been possible for the writer to recognize, especially by the graptolites, the marked extension of the outcrops of the Viola limestone and the Sylvan shale above it in the Atoka region where they have not been previously recognized, excepting that Taff (1, p. 4)[6] indicated that the String-

[4] A paper on "The Graptolites of the Viola Limestone," by Rudolf Ruedemann and the writer has been submitted to the *Bulletin* of the Geological Society of America.

[5] The distribution of most of the outcrops of the Viola is shown on a new geologic map of the Arbuckle Mountains accompanying *Bulletin 55* of the Oklahoma Geological Survey.

[6] Numbers in references correspond with numbers in the bibliography at the end of this paper.

A



B

EXPLANATION OF PLATE 1

A—Tops of Viola hills from another hill in much folded region on south side of Colbert Creek, 5 miles southwest of Davis, Oklahoma.

B—Viola hill 6.5 miles southeast of Gotebo, Oklahoma, being second from southeast of a row of four outcrops of Viola on north edge of Wichita Mountains.

town shale, Talihina chert, and Jack Fork sandstone are equivalent in age to the Viola limestone. This extends the distribution of these formations about 20 miles east of the Arbuckle Mountains to the western edge of the thrust fault system of the Ouachita Mountains. John Fitts, of Ada, Oklahoma, should receive large recognition for his help in extending correlations eastward into the Atoka region. Also, the Fernvale is exposed above the Tyner in a small outcrop 7 miles northeast of Tahlequah. The area of all these scattered outcrops of the Viola limestone aggregates about 45 square miles.

TOPOGRAPHY, STRUCTURE, AND DRAINAGE

Many of the outcrops of the Viola limestone are narrow and elongate, and as this formation is more resistant than the Simpson shales and limestones below and the Sylvan shale above, the Viola hills commonly rise several hundred feet above the formations on either side of it. These hills are as a rule elongate elliptical with evenly rounded slopes covered only with grass and short herbs and, being barren of trees on their upper slopes, they stand out as the most characteristic and noteworthy features of the topography. Plate 1, A, B, shows the characteristic form of these hills.

The structure of the Viola limestone varies greatly in different parts of the mountains. In the Lawrence quarry and in the old quarries at the southwest it is nearly horizontal; in the eastern and northeastern parts the dips are generally less than 30°; southwest of Bromide the angle of dip increases; west of Ravia the beds stand nearly vertical (Pl. 2, B) and continue so most of the distance northwestward to within a mile of U. S. Highway 77. At that highway the dip is 55° and it decreases northwestward to 30° or less east of Pooleville. In the northern part of the mountains west and southeast of Davis, the dips are generally very high and in many places practically vertical. In the Criner Hills, dips vary from about 45° to vertical, and at the northwest edge of the Wichita Mountains the dip of the Viola is 20° or less. In all of its outcrops near Atoka the Viola is vertical or nearly so. In most places the very high dips are due to folding and faulting. Some of the low dips are on the very open parts of anticlines or on an apparent monocline.

The drainage of the Viola limestone is rather insignificant as compared with that of the thicker Simpson group and the Arbuckle limestone beneath it. Many of the larger streams and some of the small creeks, all antecedent, cut across it at various angles. Several of these streams cross it through relatively narrow water gaps, and in several of these nearly the entire formation is particularly well exposed. Nu-

A

B

EXPLANATION OF PLATE 2

A—Thin beds of Viola limestone 2–6 inches thick dipping gently southeast, on south edge of John Fitts' place, 3.5 miles southwest of Bromide, Oklahoma.

B—Vertical beds of Viola limestone on west side of Oil Creek 16 miles southeast of Sulphur, Oklahoma. In foreground at left Ross Maxwell is standing at west edge of creek in middle of about 15 feet of coarsely crystalline thick-bedded Fernvale phase at top of Viola.

merous small tributaries rise in the formation, most of the shortest flowing transverse to the longer axis of outcrop. A few have developed within the Viola parallel with the longer axis and these divide it into two parallel ridges which may be a mile or more in length.

COLOR, TEXTURE, COMPOSITION, BEDDING

The color of the Viola limestone varies most commonly from gray to dark buff, but the middle and upper parts of it in its northeastern outcrops are very light gray or almost white, and many beds in the lower part contain dark brownish black blotches.

In most of its outcrops the major part of the Viola limestone is dense, fine-grained, and very tough. It is very difficult to break this part of the limestone with a hammer, and when bruised by a heavy blow, much of the limestone emits a very distinct petroleum odor. Coarsely crystalline beds occur at some localities near the base, some near the middle, and more near the top where they grade into the typically coarsely crystalline dark gray limestone of the Fernvale phase. (See heavier beds at the left of the center of Plate 2, B, in which two of the thick beds have shown greater resistance to erosion.) In the northeastern part of the mountains most of the middle and upper parts of the Viola are coarsely crystalline.

The formation consists primarily of limestone, part of which is relatively pure, though it may contain silicon up to 50 per cent or more. The high silicon content is generally due to the presence of chert, though southeast of Franks there is much sand in the lower part. In some beds small scattered chert nodules occur and in others so many large nodules that some beds seem to consist very largely of chert. In several areas a cherty zone occurs near the base and another near the top, but others may be scattered through the formation. In the southwestern and western parts of the mountains a marked shaly zone occurs in a position ranging from 100 to 150 feet above the base, but at Rock Crossing in the Criner Hills the shaly zone occurs near the base.

The formation is in general well bedded, occurring most commonly in layers ranging from 2 to 6 inches thick (Pl. 2, A), but a few layers are a foot or more in thickness. Particularly near the base the bedding planes are smooth, and the beds are even in thickness for long distances, but in many of the outcrops, the beds near the middle and some in the upper part are extremely irregular, and nearly the entire bedding planes consist of elevations and irregularly rounded depressions, with some shaly material in the depressions. These beds with

rough bedding planes are well illustrated in the old quarry on the east side of U. S. Highway 77, 2.5 miles north of Springer.

THICKNESS

Taff's early statement is:

> On the whole the Viola limestone varies but slightly in thickness and general characteristics throughout its occurrence in the Arbuckle Mountain region. (3, p. 24.)

However, when measured in many sections, it is found to vary from 195 feet in thickness in the eastern end of the mountains to 929 feet at the west end, and the thickness on Highway 77 is 836 feet, and on Colbert Creek at the north it has a thickness of 645 feet. The thickness at the north end and in the middle of the Criner Hills is almost as much as on West Spring Creek (Table I).

TABLE I

THICKNESS IN FEET OF VIOLA LIMESTONE AND FERNVALE PHASE

	Dip in degrees	*Viola Proper*	*Fernvale Phase*	*Total*
West Spring Creek Sec. 1, T.2S., R.2W.	25–28	883	46	929
U. S. Highway 77 Sec. 25, T.2S., R.1E.	55	808	28	836
West Branch Sycamore Creek Sec. 27, T.3S., R.4E.	75	662	24	686
Witch Hole Sec. 2, T.2S., R.7E.	28–35	431	92	523
Robertson Ranch Sec. 20, T.2S., R.8E.	65	165	30	195
Northeast of Bromide Sec. 32, T.1S., R.8E.	5–10	205	82	287
5 miles north of Bromide Sec. 18, T.1S., R.8E.	10	420	70	490
P. A. Norris Ranch Sec. 2, T.1N., R.8E.	20	313	78	391
On Murray Lane Sec. 12, T.1N., R.6E.	22	342	85	427 on road
2 miles west of Nebo Secs. 20, 21, T.2S., R.3E.	12	738	0	738*
Colbert Creek Sec. 15, T.1S., R.1E.	70			645*
Rock Crossing, Criner Hills Sec. 35, T.5S., R.1E.	45	(near base only)		75
North end, Criner Hills Sec. 9, T.5S., R.1E.	80	857	32	889*
Middle of Criner Hills Sec. 27, T.5S., R.1E.	45	828	80	908
South of Gotebo Secs. 13, 14, T.6N., R.16W.	16	517	59	576*
Grant's Gap, north of Stringtown Sec. 3, T.1S., R.12E.	90	502	0	502

* Paced, others measured with tape.

AGE AND CORRELATION

The Viola limestone is considered upper Ordovician in age and Taff has correlated it with Trenton, Utica, Frankfort, Lorraine, and Richmond (2, pp. 3, 4).

STRATIGRAPHIC RELATIONS

In the central and western part of the Arbuckle Mountains the Viola limestone is apparently conformable on the top of the Bromide formation of the Simpson group. Though studied carefully at several localities in the part of the mountains just noted, no stratigraphic break was discovered, the only physical change being from the heavy beds at the top of the Bromide to thin beds in the Viola, though some of the latter near the base of the formation may have chert included in them.

However, a different condition prevails in the eastern part of the mountains and at Rock Crossing in the Criner Hills (Pl. 3, A, B). At several places northwest of Bromide a conglomerate occurs at the base of the Viola. At some localities this conglomerate contains limestone pebbles and in others rounded chert pebbles. At Rock Crossing the base of the Viola rests on a 2-3-inch clay bed covered with a thin layer of bog iron. In these areas where evidence of the stratigraphic break is clear and in other parts of the eastern region where these evidences are not found, there is faunal evidence of a hiatus between the formations. The fauna in the basal part of the Viola at Rock Crossing and in the northeastern part of the Arbuckle Mountains corresponds with a zone 100–150 feet above the base of the Viola in the middle and western parts of the mountains. The clay bed and conglomerate seem to give clear evidence of weathering and erosion, and elsewhere the hiatus may be represented simply by non-deposition.

Near the top, the typical Viola seems to grade into the coarsely crystalline Fernvale phase above, and generally the Fernvale grades through argillaceous limestone to calcareous shales of the Sylvan formation above. At one locality, where the Fernvale is exceptionally thin (24 feet), considerable pyrite and limonite are present at the contact of the rough limestone surface with the Sylvan shale above. Only at this one place has any suggestion of an unconformity been noted, and no clear evidence was noted there. However, rather marked variation in thickness of the Fernvale in relatively short distances seems to give evidence of disconformity at some localities, and on U. S. Highway 77, 4 miles south of Davis and 2.5 miles west of Nebo, the Fernvale is absent. In the Atoka region the Viola seems to rest con-

A

B

EXPLANATION OF PLATE 3

A—Conglomerate base of Viola 1.5 miles south of Franks, Oklahoma. Not only here, but at several localities southeast, Viola contains basal conglomerate separating it from Simpson formations beneath it. Throughout area where these conglomerates occur there is absence of basal zone of Viola, which in western part of Arbuckle Mountains attains thickness of 100–150 feet.

B—Thin residual clay and bog iron ore bed at the base of Viola at Rock Crossing of Hickory Creek near south end of Criner Hills about 7 miles southwest of Ardmore. Graptolite zone at base of Viola here, as in zone south of Franks, occurs 100–150 feet above base of Viola in southwest edge of Arbuckle Mountains about 20 miles north of Criner Hills.

formably on the Stringtown shale below and grade conformably into the Sylvan shale above, though no Fernvale is found in that region. Possibly a gradational zone of alternating shale and cherty limestone near Atoka may represent the Fernvale elsewhere.

FAUNA

The two groups of fossils which are most persistent and most widespread are the graptolites and trilobites. In most of the sections representatives of these two groups may be found from bottom to top of the formation with only a few narrow intervals in which they are wanting. However, nearly all of the other groups of invertebrates are represented, though some of them only in a minor degree. Taff (3, pp. 24, 25) lists the fossils of the Viola identified by E. O. Ulrich in three members (Table II).

TABLE II

FOSSILS OF LOWER MEMBER OF VIOLA LIMESTONE

Streptelasma profundum var.
Tetradium columnare Hall
Homotrypa intercalaris Ulrich
Bythopora subgracilis Ulrich
Phylloporina reticulata Hall
Rhinidictya mutabilis Ulrich
Rhinidictya mutabilis major Ulrich
Escharopora subrecta Ulrich
Phaenopora incipiens Ulrich
Arthropora bifurcata Ulrich
Plectambonites sericeus var.
Strophomena filitexta Hall
Rafinesquina deltoidea Conrad
Dalmanella hamburgensis ? Walcott
Dinorthis pectinella Hall
Platystrophia sp. undetermined (small)
Rhynchotrema increbescens Hall
Zygospira recurvirostris Hall
Vanuxemia gibbosa Ulrich
Technophorus subacutus ? Ulrich
Cyrtoliles retrorsus Ulrich
Protowarthia pervoluta U. and S.
Lophospira bicincta Hall
Strophostylus textilis U. and S.
Holopea obliqua ? Hall
Pterotheca attenuata Hall
Bumastus trentonensis Emmons

FOSSILS OF MIDDLE MEMBER (TRINUCLEUS BEDS) OF VIOLA LIMESTONE

Diplograptus pristis ? Hall
Climacograptus typicalis Hall
Schizotretra minutula W. and S.
Conotreta sp. undetermined (*rusti* ? Walcott)
Rafinesquina deltoidea Conrad
Conularia trentonensis Hall
Trinucleus concentricus Eaton
Trinucleus sp. undetermined
Proetus parviusculus var.
Pterygometopus (near *callicephalus* Hall)
Nileus vigilans Meek and Worthen

FOSSILS OF UPPER MEMBER OF VIOLA LIMESTONE

Bead-like joints of stalk of undescribed crinoid or cystid, ¼ inch in thickness
Pachydictya gigantea Ulrich
Ptilotrypa obliquata Ulrich
Plectambonites sp. nov. (with denticulate hinge)
Strophomena wisconsinensis Whitfield
Leptaena unicostata M. and W.
Rafinesquina sp. nov. (near *camerata*)
Orthis kankakensis sweeneyi Winchell
Dinorthis subquadrata Hall
Dinorthis proavita W. and S.
Hebertella insculpta Hall
Dalmanella macrior Sardeson
Platystrophia acutilirata Conrad
Rhynchotrema capax Conrad
Parastrophia divergens H. and C.

From these lists of fossils, Taff correlates lower Viola with latest Black River and earliest Trenton, middle Viola with latter half of

Trenton, and upper Viola with Richmond. With the exception of the Black River, this agrees rather closely with his correlation in the Tishomingo Folio previously noted, where he makes the Viola correspond with all the formations, Trenton, Utica, Frankfort, Lorraine, and Richmond. This correlation made by Taff 30 years ago seems to hold at present, as various species of fossils occurring in these formations are found in corresponding parts of the Viola.

Two sponges, *Ischadites* cf. *iowensis* and *Receptaculites* cf. *oweni*, occur in the Trenton and Galena. Of the 30 different graptolites in the Viola, 5 occur in the Normanskill, 7 in the Trenton, 9 in the Utica, 4 in the Lorraine, 2 in the Richmond, and 7 in the Hartfell shales of Scotland and Ireland. *Strepelasma* cf. *profundum* is common in the zone with the sponges. The brachiopods of the Viola are fairly well represented in all four of the formations; the conularids seem to be mostly Trenton; the cephalopods are best developed in the Trenton and Richmond, and some of these, according to Foerste, seem to relate the Viola with Baffin Island far north, the Red River formation of Lake Winnipeg region, and possibly also with southwest Texas. The trilobites which are scattered from bottom to top of the formation are represented most largely by Trenton forms. The *Cryptolithus tessellatus* Green, practically at the base in some sections, extends up into the Richmond-Fernvale phase at the top. One particularly noteworthy form, *Robergia athenia* Ulrich, has been found on U. S. Highway 77, at the northeast edge of Bromide and 2 miles west of Nebo Store, south of Sulphur, but it is especially common at the last of the three localities. The genus *Robergia* is common in Scandinavia and it occurs at Saltville, Virginia, and in the Athens shale of Alabama (10, p. 111). The fact that this species *R. athenia* is common in both the Viola limestone and the Athens shale suggests that probably part of the Athens should be raised from its position in the Chazyan up to the upper Black River or lower Trenton. This suggestion finds added significance in that the Athens shale has been correlated with the Normanskill shale of New York (10, p. 109). Part of the Normanskill shale has been correlated by Ruedemann with the Black River (17, p. 279), and the Rysedorph conglomerate, which locally seems to lie in the upper part of the Normanskill, contains typical Trenton fossils in its pebbles.

In Table III and Table IV the graptolites and other invertebrates are listed by zones from 15 different localities.

Though there are some very special developments of local faunas, as the one at the southeast edge of Double Mound about one mile southwest of the Lawrence quarry, Table III and Table IV demonstrate that most of the forms are rather widespread in their distribu-

TABLE III

List of Graptolites by Zones

(Figures at top of columns refer to localities, those in table to zones)

Localities	*1*	*2*	*3*	*4*	*5*	*7*	*8*	*8a*	*9*	*10*	*11*	*13*	*14*
Climacograptus caudatus Lapworth	12	11											
C. eximius Ruedemann	8, 12	7, 8, 11	11, 13		5, 6	4		2			4	3	
C. lorrainensis Ruedemann	2	3	7		4		3						
C. spinifer Ruedemann				b	5, 6			21	6, 11	b	4	3	5
C. typicalis Hall	4, 8, 9	5, 7, 8, 10, 11	11, 12, 13, 14	b	5, 6	4	4	2, 21	11	b	4	3	4, 5
C. typicalis crassimarginalis n. var. R. and D.	8, 12	10, 11	12, 13, 14	b	6	4			11	b	4		
C. typicalis posterus Ruedemann		3					3				4		
Corynoides curtus Lapworth											4		
Cryptograptus insectiformis Ruedemann	9		13	b						b	4		
Desmograptus oklahomensis n. sp. R. and D.					6								
Dicellograptus forchammeri (Geinitz)										b			
D. forchammeri flexuosus Lapworth		10	13	b	6			(2?)		b	4	3	5
D. gurleyi Lapworth		10								b	4		
D. sextans var. *perexilis* Ruedemann					6								
Dicranograptus nicholsoni geniculatus n. var. R.&D.	9			b		4			11	b	4		
D. nicholsoni longibasalis n. var. R. and D.								21	11	b			
Diplograptus (*Amplexograptus*) *amplexicaulis* Hall	9		13							b			
D. nexus Ruedemann		7	7, 8			4							
D. peosta Hall	2	1											
D. recurrens Ruedemann	2, 3, 4, 5	3, 5, 6	7		4							2	3
D. vespertinus Ruedemann	8, 9, 12	6, 10	13, 14		6	4			11	b	4		
Glossograptus ciliatus Emmons	9									b			
G. quadrimucronatus (Hall)	7, 9, 12 (3?)	6, 10	7, 8, 11, 14		6	4				b			3, 4
G. quadrimucronatus spinigerus (Lapworth)	7, 9	7, 13, 14	13	b	6	4				b	4	3	
Lasiograptus (*Thysanograptus*) *eucharis* (Hall)	4	10	11, 13	b	6	4			11	b	4		
Leptograptus annectans (Walcott)		10											
L. capillaris Caruthers		10											
L. flaccidus Hall	9	10	13	b						b	4		
L. flaccidus macer Elles and Wood	9	10	13	b	6	5				b	4	3	
L. flaccidus trentonensis Ruedemann				b	6				11	b	4		
Mastigograptus circinalis Ruedemann				b						b	4		
M. cf. *gracillimus* Lesquereux					4, 6				11	b			

The numbers of zones in each of the above sections vary greatly as given below:
1. West Spring Creek, 12 zones. 2. U. S. Highway 77, 11 zones. 3. West Branch Sycamore Creek, 14 zones. 4. Two miles west of Nebo, base. 5. Witch Hole, 6 zones. 6. West edge of Bromide, middle and lower. 7. Northeast edge of Bromide, 9 zones. 8. Five miles north of Bromide, 5 zones. 8a. Murray Lane, 23 zones. 9. P. A. Norris Ranch, 11 (basal part wanting). 10. Rock Crossing (lower, with basal part wanting). 11. Middle of Criner Hills, 4 zones. 12. South of Gotebo, 3 zones. 13. Northeast of Atoka, 4 zones. 14. Grants Gap, northeast of Stringtown, 5 zones.

tion. Two zones are very clearly developed in every part of the Arbuckle Mountains, and they occur also in the Criner Hills. These two zones are the main graptolite zone not far above the base of the Viola and the coarsely crystalline Fernvale phase at the top. Though the latter does not occur at Rock Crossing, it is well developed in the middle and northern parts of the Criner Hills. Between these two zones many graptolites, brachiopods, and trilobites have been found in such a way in their respective zones as to bind the Viola in its numerous outcrops into a single formation, excepting that elsewhere in its wide distribution, the Fernvale has been recognized as a separate formation. Probably here with its typical Richmond fauna, it should be separated in a similar way, though it was originally included in the Viola, and if one were to consider its relations from the standpoint of local stratigraphy alone, it would seem most natural to consider it a phase or member of the Viola formation. Doubtless more extended collections would serve to demonstrate still more clearly the unity of the formation in this region. Evidence to this end has been secured nearly every time the localities have been revisited to make additional collections from the Viola. Until recently *Robergia athenia* Ulrich was known only from the locality 2 miles west of Nebo and at the northeast edge of Bromide, on the east side of Washita River, but recently this species was found west of the river, on U. S. Highway 77.

Also, until recently, the tiny graptolite *Cryptograptus insectiformis* Ruedemann was known only from three localities west of Washita River and from the locality 2 miles west of Nebo about 3 miles east of the river, but recently it has been found in the Viola south of the town of Mill Creek, extending its distribution nearly 10 miles farther eastward. As this is a very tiny form, further search may be rewarded with evidence of much wider distribution. The Viola limestone is so tough that crowbars and heavy sledge hammers are needed in addition to light collecting hammers to break it most effectively, and a very considerable strength of arm and back are needed as well as interest and perseverance. However, the work thus far expended on this formation has been richly rewarded by the beautifully preserved fossils (30 graptolites in *Bulletin* of the Geological Society of America). Two additional species, *Corynoides curtus* Lapworth and *Leptograptus flaccidus* Hall, have been identified and included in Table IV. Further search would doubtless reveal the presence of other species and varieties and give still further significant evidence not only of the relation of various parts of the Viola in Oklahoma, but also of the relation of the Viola to far distant formations in North America and Europe.

6. West edge of Bromide, middle and lower. 7. Northeast edge of Bromide, 9 zones. 8. Five miles north of Bromide, 5 zones. 8a. Murray Lane, 3 zones. 9. P. A. Norris Ranch, 11 (basal part wanting). 10. Rock Crossing (lower, with basal part wanting). 11. Middle of Criner Hills, 4 zones. 12. South of Gotebo, 3 zones. 13. Northeast of Atoka, 4 zones. 14. Grants Gap, northeast of Stringtown, 5 zones.

TABLE IV

LIST OF OTHER INVERTEBRATES BY ZONES

(Figures at top of columns refer to localities, those in table to zones)

Localities	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*8a*	*9*	*11*	*12*	*13*
Ischadites cf. *iowensis* Owen									6	7			
Receptaculites cf. *oweni* (Hall)									6	7		6	
Streptelasma profundum (Conrad)						X	2		5	7			
Crania laelia Hall	9	10	13										
C. cf. *setigera* Hall					6		2						
Dalmanella sp.		5				X	3	5	2	3			
Dinorthis (*Plaesiomys*) *subquadrata* (Hall)	1		1				2	1					
Hebertella crispata (Emmons)										11			
Leptaena unicostata Meek and Worthen	5		6, 7										
Leptobolus insignis Ruedemann	9			b	5		4		21	11			
Lingula cf. *elderi* Whitfield							4	4					
L. modesta Ulrich			13										
L. philomela Billings	2, 3, 4, 7, 8	2, 3	5		4, 5	X	5			7			
L. riciniformis galenensis W. and S.			13		6								
Parastrophia hemiplicata Hall					6		4						
Platystrophia sp.								4	5	6, 7			
Plectambonites sericeus var.? (Sowerby)	5	5	5		2		2	2, 3, 4, 5		7			
Rafinesquina alternata (Emmons)	7		7		4, 6	X	1	2, 4		7, 11			
R. alternata centristriata Ruedemann			7		4, 6		2, 3, 4	4, 5					
R. deltoidea (Conrad)					6	X	2, 3, 4, 5	4, 5		7			
R. mucronata Foerste					6								
Rhynchotrema ainsliei Winchell					6								
R. capax (Conrad)	1	1	1		1		1	1	1	1		1	
R. increbescens (Hall)		4			5	X	2, 3, 5	2, 5					
Schizambon minutus Ruedemann			12		1								
Schizotreta minutula W. and S.	7		6, 7, 12		6								
Strophomena cf. *incurvata* (Shepard)			9			X							
Zygospira recurvirostris (Hall)	7	11						5		11			
Chasmatopora fenestra (Hall)								4					
Escharopora recta Hall								4, 7, 8					
Prasopora simulatrix Ulrich								6	8	7, 8			

Ambonychia orbicularis (Emmons)								4, 7					
Ctenodonta gibbosa (Hall)						X	4			3, 6			
Cyrtodonta subangulata (Hall)					2		2			3, 6, 7			
Clathrospira cf. *conica* Ulrich and Scofield							3	4					
Hormotoma gracilis (Hall)			9										
Liospira americana (Billings)								4					
L. vitruria (Billings)			12				4						
Sinuites cancellatus (Hall)			8				6, 8	6, 7, 8		9			
Conularia papillata (Hall)								4					
C. trentonensis (Hall)	3		5, 7, 11		6		4			6			
Cycloceras cf. *olorus* (Hall)			6										
Endoceras cf. *proteiforme* Hall		6	3										
Diestoceras cf. *whiteavesi* Foerste								4					
Geisonoceras sp.? Ruedemann					6								
Orthoceras cf. *sociale* Hall		2										1	
O. strigatum Hall	7	6											
Ontoceras cf. *pupaeforme* Ruedemann										11			
Spyroceras cf. *bilineatum* (Hall)					6								
Westonoceras sp.			3			X		4, 7		6			
Whiteavesites sp.			3					3					
Cryptolithus tessellatus Green	2, 3, 5, 8, 9, 12	1, 2, 3, 6, 7, 10, 11	2, 3, 4, 5, 6, 7, 8, 9, 11, 13, 14	b	3, 4, 5, 6		4, 5			11	2, 4	3	3
Amphilichas trentonensis (Conrad)										11			
Gerasaphes ulrichana Clarke		3, 7, 8	7, 11		5		4			7, 11			
Illaenus cf. *latidorsatus* Hall	8		13										
Isotelus gigas deKay	2, 3	5, 7, 8	5, 6, 7, 8, 9, 11, 13		5, 6	X	2, 3, 4, 5	4, 7	8	5, 7, 11		3	
I. maximus Locke	1		6				1				4		
I. latus Raymond	5, 7	5, 7											
Nileus vigilans (Meek and Worthen)	9		8, 9				4			7, 11			
Robergia athenia Ulrich		10		b			4						
Thaleops ovatus Conrad								4		7			
Ceraurus pleurexanthemus Green										11			

Note: b means near base; X means present.

Numbers refer to same localities as given below graptolite table, as follow:

1. West Spring Creek
2. U. S. Highway 77
3. West Branch Sycamore Creek
4. Two miles west of Nebo
5. At Witch Hole
6. West edge of Bromide
7. Northeast edge of Bromide
8. Five miles north of Bromide
8a. Murray Lane
9. P. A. Norris Ranch
10. Rock Crossing, Criner Hills
11. Middle of Criner Hills
12. Northwest hill south of Gotebo
13. North branch of Muddy Boggy Creek
14. Grant's Gap north of Stringtown

The zones differ greatly in thickness and in relative position in the different sections. This may be illustrated by the position of the lower main graptolite horizon, which is in zone 9 on West Spring Creek, base of 10 on U. S. Highway 77, 13 on the West Branch of Sycamore Creek, lower part of 6 at the Witch Hole, 4 at the northeast edge of Bromide, 21 on Murray Lane, 11 on P. A. Norris Ranch, at the base of the thin section at Rock Crossing in the Criner Hills, and 83 feet above the base in the middle of the Criner Hills. The character of the various parts of the formation and the distribution of the fossils are shown in Sections 1–14 and Tables III–IV.

SECTION 1

WEST SPRING CREEK, 3.5 MILES SOUTHEAST OF POOLEVILLE, SEC. 1, T.2S., R.2W., AND SEC. 6, T.2S., R.1W.

Dip, 25°–28°, strike, N.40° W.

Zone No.	*Thickness in Feet* *Zone*	*Total*	*Description*
1	46	46	Fernvale. Coarse-grained gray limestone rather massive at top but better bedded near base. Contains *Diplograptus peosta* Hall, *Dinorthis subquadrata* Hall, *Lingula* sp., and three other small brachiopods, *Rhynchotrema capax* (Conrad) and fragments of three cephalopods and of a large trilobite, *Isotelus* cf. *maximus* Locke
			Viola Limestone Proper
2	30	76	Dense fine-grained dark gray-to-buff and brown limestone in beds 2–7 inches thick with chert present as nodules. *Diplograptus peosta* Hall, *D. recurrens* Ruedemann, *Climacograptus lorrainensis* Ruedemann, *Lingula* cf. *philomela* Billings, *Cryptolithus tesselatus* Green, and *Isotelus* sp.
3	56	132	Dense fine-grained dark gray limestone in beds 2–14 inches thick with much chert. *Diplograptus recurrens* Ruedemann, *Glossograptus* sp., *Lingula philomela Billings, Conularia trentonensis* Hall, *Cryptolithus tesselatus* Green, *Isotelus* cf. *gigas* deKay
4	53	185	Fine-grained brownish limestone in beds 1–10 inches thick containing chert. *Diplograptus recurrens* Ruedemann, *Climatograptus* cf. *typicalis* Hall, *Lasiograptus* cf. *eucharis* Ruedemann, *Lingula philomela* Billings, *Zygospira recurvirostris* (Hall)
5	64	249	Fine-grained chocolate-brown limestone. *Diplograptus recurrens* Ruedemann, *Leptaena* cf. *unicostata* Meek and Worthen, *Lingula* sp., *Orthoceras* sp., *Cryptolithus tessellatus* Green, *Isotelus gigas* Green, *I. latus* Raymond
6	109	358	Fine-grained bluish gray-to-chocolate-brown limestone. *Lingula* cf. *philomela* Billings, *Zygospira recurvirostris* (Hall), *Isotelus latus* Raymond
7	115	473	Very fine-grained limestone with a little chert, brown-to-dark gray. *Glossograptus quadrimucronatus* (Hall), *Lingula* cf. *philomela* Billings, *Schizotreta minutula* Winchell and Schuchert, *Orthoceras strigatum* Hall, *Isotelus* sp.
8	220	693	Fine-grained gray-to-yellow limestones, earthy in appearance, little chert. *Climacograptus eximius* Ruedemann, *C. typicalis crassimarginalis* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Leptograptus flaccidus macer* Elles and Wood, *Leptobolus insignis* Ruedemann, *Lingula* cf. *philomela* Billings, *Cryptolithus tessellatus* Green, *Illaenus* cf. *latidorsatus* Hall

SECTION 1 (*Continued*)

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
9	84	777	Dark gray-to-dense blue lithographic limestone with much chert. Argillaceous in graptolite zone. *Diplograptus* (*Amplexograptus*) *amplexicaulis* (Hall), *Climacograptus typicalis crassimarginalis* Ruedemann and Decker, *Cryptograptus insectiformis* Ruedemann, *Dicranograptus nicholsoni geniculatus* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Glossograptus ciliatus* Emmons, *Glossograptus quadrimucronatus spinigerus* Lapworth, *Leptograptus flaccidus* Hall, *L. flaccidus macer* Elles and Wood, *Crania* cf. *laelia* Hall, *Cryptolithus tessellatus* Green
10	95	872	Thin-bedded, cherty, much jointed, grayish brown limestone exposed in flood plain south of stream channel. No fossils found
11	25	897	Even-bedded dense brown limestones 4–8 inches thick exposed in south one of two stream channels
12	32	929	Thin gray-to-brown cherty limestones laminated and some sandy. *Climacograptus caudatus* Lapworth, *C. eximius* Ruedemann, *C. typicalis crassimarginalis* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Glossograptus quadrimucronatus* Hall, *Cryptolithus tessellatus* Green
			Total thickness, 929 feet

SECTION 2

ON HIGHWAY 77, 2.25 MILES NORTH OF SPRINGER, SEC. 25, T.2S., R.1E.

Dip, 55° SW.

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
1	28	28	Fernvale member, 28 feet. Dark gray coarsely crystalline limestones in beds 4–14 inches thick. *Diplograptus peosta* Hall, *Rhynchotrema capax* (Conrad), fragments of cephalopods, *Cryptolithus tessellatus* Green
2	4	32	Coarse gray limestone with chert. *Lingula* cf. *philomela* Billings, *Orthoceras* cf. *sociale* Hall, *Cryptolithus tessellatus* Green, *Gerasaphes ulrichana* Clarke
3	34	66	Chiefly fine-grained dense limestones with some coarse gray beds interspersed. Beds rough and irregular with some shale partings filling hollows in the uneven surfaces. *Climacograptus lorrainensis* Ruedemann, *C. typicalis posterus* Ruedemann, *Diplograptus recurrens* Ruedemann, *Lingula philomela* Billings, *Cryptolithus tessellatus* Green, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay
4	34	100	Thin-bedded fine-grained, dark gray-to-brown limestone almost chocolate-colored with much chert. *Rhynchotrema increbescens* (Hall)
5	119	219	Limestones of varying texture, some coarse gray but more fine chocolate-colored. Beds uneven with shale filling in hollows in irregular surfaces. *Climacograptus typicalis* Hall, *Diplograptus recurrens* Ruedemann, *Dalmanella* sp., *Plectambonites* cf. *sericeus* (Sowerby), *Isotelus gigas* deKay, *Isotelus latus* Raymond
6	205	424	Fine-grained grayish blue dense limestone, weathers to grayish white, contains chert. *Diplograptus recurrens* Ruedemann, *D.* cf. *vespertinus* Ruedemann, *Glossograptus quadrimucronatus* Hall, *Orthoceras strigatum* Hall, *Cryptolithus tessellatus* Green, *Isotelus* sp. fragments, a few barrel-shaped crinoid stem or arm fragments
7	55	479	Extends from base of lower test pit on north slope of hill to bench in top of quarry. Thin irregularly bedded limestone

SECTION 2 (*Continued*)

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
			with chert. *Climacograptus eximius* Ruedemann, *C. typicalis* Hall, *Diplograptus nexus* Ruedemann, *Cryptolithus tessellatus* Green, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay, *Isotelus* cf. *latus* Raymond
8	74	553	Extends from bench near top of quarry to wall at base. Gray irregularly bedded limestones with rough surfaces alternating with shaly layers. A little asphalt in cracks. Surface of inclined wall at base very fossiliferous. *Climacograptus typicalis* Hall, *C. eximius* Ruedemann, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay
9	58	611	Extends from base of quarry to top of good exposure along road on east side, bed 10 feet high. Thin limestones, some shale. No fossils found
10	119	730	Extends from good 10-foot high exposure to base of 20-inch bed and to top of more cherty thinner beds. Gray-to-buff limestone with shale. Beds 2–15 inches thick. Little chert. Graptolites especially in lower 40 feet. *Climacograptus typicalis crassimarginalis* Ruedemann and Decker, *Dicellograptus forchammeri flexuosus* Lapworth, *D. gurleyi* Lapworth, *Diplograptus vespertinus* Ruedemann, *Lasiograptus eucharis* Hall, *Leptograptus annectans* Ruedemann, *L. flaccidus* Hall, *L. flaccidus macer* Elles and Wood, *Crania laelia* Hall, *Cryptolithus tessellatus* Green, *Robergia athenia* Ulrich
11	106	836	Extends from top of thin cherty beds to base of Viola. Beds thin, very cherty. Graptolites scattered sparsely through zone. *Climacograptus eximius* Ruedemann, *C. caudatus* Lapworth, *C. typicalis crassimarginalis* Ruedemann and Decker, *Zygospira recurvirostris* (Hall), *Cryptolithus tessellatus* Green
			Total thickness, 836 feet

SECTION 3

WEST BRANCH OF SYCAMORE CREEK 20 MILES SOUTHEAST OF SULPHUR, SEC. 27, T.3S., R.4E.

Dip, 75° SW., strike, N. 65° W.

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
1	2	2	Contact with Sylvan shale above forms rough surface. Coarse gray-to-pink limestone containing brown spots. *Dinorthis subquadrata* (Hall), *Rhynchotrema capax* (Conrad)
2	6½	8½	Gray-to-buff coarsely crystalline limestone with beds 9–14 inches thick. *Cryptolithus tessellatus* Green
3	6	14½	Medium, gray, crystalline limestones in beds 4–6 inches thick. *Lingula* sp., *Rhynchotrema capax* (Conrad), *Endoceras proteiforme* (Hall), *Westonoceras* sp., *Whiteavesites* sp., *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay
4	9¼	23¾	Very resistant, coarsely crystalline limestones, gray with brown spots. First four zones constitute Fernvale phase. *Lingula* sp., *Strophomena* sp., *Isotelus* fragments, *Cryptolithus tessellatus* Green
5	38	61¾	Thin-bedded, gray, finely crystalline limestone in beds 3–5 inches thick. Cherty with sandy zone near base. *Diplograptus recurrens* Ruedemann, *Lingula* cf. *philomela* Billings, *Plectambonites* cf. *sericeus* (Sowerby), *Conularia* cf. *trentonensis* Hall, *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay
6	75	136¾	Resistant 8-inch ledge at top. Most beds 2–4 inches thick, but thicken and become more rough and cherty toward base, *Cycloceras* cf. *olorus* (Hall), *Cryptolithus tessellatus* Green, fragments of *Isotelus*

SECTION 3 (*Continued*)

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
7	20	156¾	Massive 2-foot ledge at top of zone, fine-grained, gray thinner beds below. Beds 1–3 inches thick. *Climacograptus lorrainensis* Ruedemann, *Diplograptus nexus* Ruedemann, *D. recurrens* Ruedemann, *Glossograptus quadrimucronatus* Hall, *Leptaena unicostata* Meek and Worthen, *Rafinesquina alternata* (Emmons), *Schizotreta minutula* Winchell and Schuchert, *Cryptolithus tessallatus* Green, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay
8	45½	202¼	Thin rough fine-grained limestone in beds 1–2 inches thick. Little chert in scattered nodules. Graptolites and trilobites scattered through zone, but graptolites abundant 11 feet above base. *Diplograptus nexus* Ruedemann, *Glossograptus quadrimucronatus* Hall, *Sinuites cancallatus* (Hall), *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay, *Nileus vigilans* Meek and Worthen
9	53¾	255¼	Even-bedded limestones 1–3 inches thick. A little chert in elongate stringers parallel with beds. *Strophomena* cf. *incurvata* (Shepard), *Hormotoma* sp., *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay, *Nileus vigilans* Meek and Worthen
10	15	270½	Fine gray crystalline limestone in beds 2–4 inches thick. Beds irregular with rough surfaces and more chert than in zone above
11	72	342½	Light gray limestones at top, darker lower down. Beds thicker near top, one 8-inch bed in middle. Beds 2–6 inches in lower part. Graptolites and trilobites more abundant near top. *Climacograptus eximius* Ruedemann, *C. typicalis* Hall, *Glossograptus quadrimucronatus* Hall, *Lasiograptus eucharis* (Hall), *Lingula* cf. *bisulcata* Ulrich, *Conularia* cf. *Trentonensis* Hall, *Cryptolithus tessellatus* Green, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay
12	100	442½	Thin dark gray dense limestone without chert. Beds generally 2–5 inches thick but increase to 9 inches near base. *Climacograptus typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Schizambon minutus* Ruedemann, *Schizotreta minutula* Winchell and Schuchert, *Liospira vitruria* Billings, fragments of trilobites
13	148	590½	Gray and brownish limestones with chert in upper part and very little near base, shaly partings prominent in lower part. Thin beds at top increase to thickness of 4–9 inches in lower part. Shaly partings near base of zone. *Amplexograptus amplexicaulis* (Hall), *Climacograptus eximius* Ruedemann, *C. spinifer* Ruedemann, *C. typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Cryptograptus insectiformis* Ruedemann, *Dicellograptus forchammeri flexuosus* Lapworth, *Diplograptus vespertinus* Ruedemann, *Glossograptus quadrimucronatus spinigerus* Lapworth, *Lasiograptus eucharis* (Hall), *Leptograptus flaccidus* Hall, *Leptograptus flaccidus macer* Elles and Wood, *Crania laelia* Hall, *Lingula modesta* Ulrich, *Lingula riciniformis* var. *galenensis* Winchell and Schuchert, *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay
14	95	685½	Even-bedded dark gray-to-brown limestones, dense-to-very finely crystalline. Distinct shaly partings in lower part of zone. Basal beds apparently in conformable contact with top of Bromide beneath. Graptolites occur throughout zone, but particularly abundant 8.5 feet above base. *Climacograptus typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Glossograptus quadrimucronatus* Hall, *Cryptolithus tessellatus* Green

Total thickness, 686 feet

SECTION 4

TWO MILES WEST OF NEBO, SECS. 27, 28, T.2S., R.3E.
Dip, 12° W.

The Viola here is 738 feet thick with no Fernvale phase present. (The Fernvale is absent also on U. S. Highway 77, 4 miles south of Davis.) As much of the Viola section west of Nebo is covered with sod, the detailed study of zones has not been attempted. However, there is a fossiliferous horizon about 75 feet above the base, in a fine-textured light buff limestone from which the following forms have been collected: *Climacograptus spinifer* Ruedemann, *C. typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Cryptograptus insectiformis* Ruedemann, *Dicellograptus forchammeri flexuosus* Lapworth, *Dicranograptus nicholsoni geniculatus* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Glossograptus quadrimucronatus spinigerus* Lapworth, *Lasiograptus eucharis* (Hall), *Leptograptus flaccidus* Hall, *L. flaccidus macer* Elles and Wood, *L. flaccidus trentonensis* Ruedemann, *Mastigograptus circinalis* Ruedemann, *Leptobolus insignis* Ruedemann, *Cryptolithus tessellatus* Green, *Robergia athenia* Ulrich

SECTION 5

WITCH HOLE 4 MILES SOUTHWEST OF BROMIDE, SEC. 2, T.2 S., R.7 E.

Zone No.	*Thickness in Feet* *Zone*	*Total*	*Description*
1	92	92	Coarsely crystalline light gray limestone in beds 1–2 feet thick. Limestone finer-grained and less crystalline nearer base and contains yellowish clay. *Rhynchotrema capax* (Conrad) occurs near base of zone which constitutes thick section of Fernvale
2	34	126	Medium-grained light gray limestone without chert. Bedding planes rough and beds 2–10 inches thick. Fragments of graptolites and *Plectambonites* cf. *sericeus* (Sowerby)
3	51	177	Covered with soil along south side of Delaware Creek
4	38	215	Dense-to-finely crystalline brownish gray limestone in beds 6–10 inches thick. Measured in stream channel. *Climacograptus lorrainensis* Ruedemann, *C. typicalis* Hall, *Diplograptus recurrens* Ruedemann, *Mastigograptus gracillimus* (Lesquereux), crinoid stem and plates, *Lingula* cf. *philomela* Billings, *Rafinesquina alternata centristriata* Ruedemann, *Rhynchotrema increbescens* (Hall), *Allodesma* sp., *Cryptolithus tessellatus* Green, *Isotelus* sp.
5	38	253	Dense-to-finely crystalline brownish gray limestone in beds 4–10 inches thick. Some thin platy layers of chert along bedding planes and some large thin lenticular chert concretions. *Climacograptus eximius* Ruedemann, *C. spinifer* Ruedemann, *C. typicalis* Hall, *Leptobolus insignis* Ruedemann, *Lingula* cf. *philomela* Billings, *Cryptolithus tessellatus* Green, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay
6	270	523	Upper part of zone has brownish gray limestones in beds 6–24 inches thick and contains much chert and some asphalt. Some graptolites and *Cryptolithus*. Middle part of zone has even beds about 5 inches thick with *Lingulas*. Lower part of zone has limestones varying in color from almost chocolate to light gray. Considerable chert. Graptolites and trilobites scattered through lower part but in great numbers about 50–75 feet above base. *Climacograptus eximius* Ruedemann, *C. spinifer* Ruedemann, *C. typicalis* Hall, *C. typicalis Crassimarginalis* Ruedemann and Decker, *Desmograptus oklahomensis* n. sp. Ruedemann and Decker, *Dicellograptus forchammeri flexuosus* Lapworth, *D. sextans perexilis* Ruedemann, *Diplo-*

SECTION 5 (*Continued*)

Zone No.	*Thickness in Feet* *Zone*	*Total*	*Description*
			graptus vespertinus Ruedemann, *Glossograptus quadrimucronatus* (Hall), *G. quadrimucronatus spinigerus* Lapworth, *Lasiograptus eucharis* (Hall), *Leptograptus flaccidus macer* Elles and Wood, *L. flaccidus trentonensis* Ruedemann, *Mastigograptus gracillimus* (Lesquereux), *Crania setigera* Hall, *Parastrophia hemiplicata* Hall, *Rafinesquina alternata centristriata* Ruedemann, *R. mucronata* Foerste, *Rhynchotrema ainsliei* Winchell, *Schizotreta minutula* Winchell and Schuchert, *Desmoceras* sp., *Geisonoceras* sp., *Spyroceras bilineatum* (Hall), *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay

SECTION 6

WEST EDGE OF BROMIDE

The following fossils were collected but the section was not measured, as much of it is soil covered on the hill slope: *Streptelasma profundum* (Conrad), *Dalmanella* sp., *Lingula philomela* Billings, *Rafinesquina alternata* (Emmons), R. *deltoidea* (Conrad), *Rhynchotrema increbescens* (Hall), *Strophomena* cf. *incurvata* (Shepard), *Ctenodonta gibbosa* (Hall), *Vanuxemia gibbosa* Ulrich, *Orthoceras* sp., *Westonoceras* sp., *Isotelus gigas* deKay

SECTION 7

NORTHEAST EDGE OF BROMIDE, SEC. 32, T.1 S., R.8 E.

Dip, 5° NE. at top, increasing to 20° near base

Zone No.	*Thickness in Feet* *Zone*	*Total*	*Description*
1	82	82	Coarsely crystalline Fernvale phase of light gray limestone. Fossiliferous horizon not far from middle contains *Rhynchotrema capax* (Conrad), *Rafinesquina alternata* (Emmons), *Isotelus maximus* (Locke)
2	16	98	Dip, 10°. Fine, light gray, crystalline limestone in beds 2–6 inches thick. Some iron stains. *Streptelasma profundum* (Conrad), *Dinorthis subquadrata* (Hall), *Plectambonites sericeus* (Sowerby), *Rafinesquina alternata centristrata* Ruedemann, *R. deltoidea* (Conrad), *Rhynchotrema increbescens* (Hall), *Cyrtodonta subangulata* (Hall), *Isotelus gigas* deKay
3	50	148	Dip 13°. Fine, light gray, crystalline limestone in beds 2–6 inches thick. Small scattered chert nodules. *Dalmanella* sp., *Rafinesquina deltoidea* (Conrad), *Rhynchotrema increbescens* (Hall), *Isotelus gigas deKay*
4	36	184	Dip, 20°, continues to base of Viola. Fine, light gray-to-buff limestone in beds 2–6 inches thick. Small irregular chert nodules. This and next zone contain main graptolite horizon of this section. *Climacograptus eximius* Ruedemann, *C. lorrainensis* Ruedemann, *C. typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Dicranograptus Nicholsoni geniculatus* Ruedemann and Decker, *Diplograptus nexus* Ruedemann, *D. recurrens* Ruedemann, *D. vespertinus* Ruedemann, *Glossograptus quadrimucronatus spinigerus* Lapworth, *Lasiograptus eucharis* (Hall), *Leptograptus flaccidus macer* Elles and Wood, *L. flaccidus trentonensis* Ruedemann, *Mastigograptus circinalis* Ruedemann, *Leptobolus insignis* Ruedemann, *Rafinesquina alternata centristriata* Ruedemann, *R. deltoidea* (Conrad), *Parastrophia hemiplicata* Hall, *Ctenodonta gibbosa* (Hall), *Liospira vitruria* (Billings), *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay, *Nileus vigilans* Meek and Worthen, *Robergia athenia* Ulrich

SECTION 7 (*Continued*)

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
5	35	219	Finely crystalline-to-dense light gray limestone in beds 2–5 inches thick, a little chert. *Climacograptus typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Leptograptus flaccidus* Hall, *L. flaccidus macer* Elles and Wood, *Lingula* sp., *Lingula* cf. *philomela* Billings, *Rafinesquina deltoidea* Conrad, *Rhynchotrema increbescens* Hall, *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay
6	17	236	More coarsely crystalline limestones, gray and yellow with brown and pink spots. Fragments of *Isotelus*, *Sinuites cancellatus* (Hall)
7	22	258	Finely crystalline gray limestone. Dark gray and weathers brown, somewhat sandy. Considerable sand in this zone 18 miles northwest
8	17	275	Coarsely crystalline gray-to-brown limestones. *Climacograptus typicalis* Hall, *Sinuites cancellatus* (Hall)
9	12	287	Thin-bedded, fine-grained gray limestone with chert
			Total thickness, 287 feet

SECTION 8

FIVE MILES NORTHWEST OF BROMIDE, SEC. 18, T.1 S., R.8 E.

Dip, 10° NE., strike, N. 35° W.

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
1	70	70	Dark gray coarsely crystalline limestone. *Rhynchotrema capax* (Conrad), *Dinorthis subquadrata* (Hall). Thickness of zone estimated, no good place to measure it
2	30	100	Fine-grained light gray limestone. Some beds porous from weathering. Beds even and 2–4 inches thick. *Plectambonites sericeus* (Sowerby), *Rafinesquina alternata* (Emmons), *Rhynchotrema increbescens* Hall
3	125	225	Fine-grained gray limestone for most part but more crystalline nearer base. *Climacograptus lorrainensis* Ruedemann, *C. typicalis posterus* Ruedemann, *Plectambonites sericeus* (Sowerby), *Rafinesquina deltoidea* (Conrad), *Whiteavesites* sp.
4	80	305	Dense-to-finely crystalline light gray limestone in beds 2–3 inches thick. Coarser in lower part of zone. *Climacograptus* sp. (poor), *Chasmatopora fenestra* Hall, *Escharopora recta* Hall, *Lingula elderi* Whitefield, *Platystrophia* sp., *Rafinesquina alternata* (Emmons), *R. alternata centristriata* Ruedemann, *R. deltoidea* (Conrad), *Plectambonites sericeus* (Sowerby), *Conularia papillata* Hall, *Ambonychia orbicularis* (Emmons), *Clathrospira conica* Ulrich and Scofield, *Liospira americana* (Billings), *Diestoceras whiteavesi* Foerste, *Westonoceras* cf. *gouldi*, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay, *Thaleops ovatus* Conrad
5	80	385	Gray limestones in beds 2–4 inches thick, but some beds up to 10 inches thick near base. A 10-inch edgewise limestone conglomerate at base of zone. This constitutes the only intraformational conglomerate known in Viola. No chert. *Dalmanella* sp., *Plectambonites sericeus* (Sowerby), *Rafinesquina alternata centristriata* Ruedemann, *R. deltoidea* Conrad, *Rhynchotrema increbescens* (Hall), *Zygospira recurvirostris* (Hall), *Bumastus trentonensis* ? Emmons
6	35	420	Fine-textured gray limestones at top, one coarsely crystalline bed in middle. Beds brownish gray and somewhat sandy nearer base. No chert excepting near base. Peculiar white bryozoans 15 feet below top of zone. *Prasopora simulatrix* Ulrich, *Sinuites cancellatus* Hall, *Conularia* sp.

SECTION 8 (*Continued*)

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
7	25	445	Upper part fine, light gray, crystalline, lower part dark brown with some sandy beds between limestones. Beds 2–5 inches thick. *Escharopora recta* Hall, *Sinuites cancellatus* (Hall), *Westonoceras* sp., *Isotelus gigas* deKay
8	15	460	Brownish gray, coarsely crystalline limestone in beds 2–4 inches thick. *Escharopora recta* Hall, *Sinuites cancellatus* (Hall)
9	15	475	Thick beds dark brown sandy limestones with others brownish gray in beds 5–14 inches thick. Most beds are dense and finely banded; a few are coarsely crystalline. Exposed beds weather porous
10	15	490	Mostly dense gray limestone, but more coarsely crystalline nearer top. Conglomerate containing limestone and chert pebbles at base of zone in unconformable contact on Bromide formation of Simpson group

Total thickness, 490 feet (paced and estimated)

(This thickness seems too great when compared with 287 feet at the northeast edge of Bromide and 391 feet on P. A. Norris Ranch, particularly when it is realized that erosion at the base at this locality has carried away the lower graptolite horizon and the 80–100 feet of beds which commonly occur below that horizon.)

SECTION 8a

MURRAY LANE, CENTER OF SEC. 12 T.1 N., R.6 E.

General dip, 22° NE. Strike, N. 20° W. Dip varies in upper faulted part of section (measurements with tape at right angles to beds and checked with alidade by Griley and Morgan. An estimated repetition by faults of 45 feet is deducted from total).

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
1	85	85	Coarsely crystalline gray limestone of Fernvale phase. *Rhynchotrema capax* (Conrad)
2	120	205	A few thick beds of light gray limestone at top. Mostly thin-bedded limestones. Considerable chert near base of zone. At base of zone: *Climacograptus eximius* Ruedemann, *C. typicalis* Hall, poorly preserved monoprionidian graptolite looks like *Dicellograptus forchammeri flexuosus* Lapworth, *Dalmanella* sp.
3	80	285	Coarsely crystalline gray-to-buff limestone. A few horizons contain chert nodules
4	34	319	Gray crystalline limestone. Brachiopods and bryozoans occur 20 feet above base
5	6½	325½	Coarse gray crystalline limestone. *Streptelasma profundum* (Conrad), *Platystrophia* sp.
6	7¾	333 1/12	Crystalline limestones in 4-foot zone with pyrite at top and bottom weathered to limonite. 1-foot zone of thin beds and 2.75 feet of massive limestone. *Ischadites* cf. *iowensis*, *Receptaculites oweni* Hall, *Platystrophia* sp.
7	20¼	353½	Dark gray coarse limestone at top, becomes buff nearer base
8	14½	367½	Buff-to-gray coarse limestones in beds 4–12 inches thick. *Prasopora simulatrix* Ulrich
9	7½	375	Mostly thin-bedded buff-to-gray limestone with much chert in nodules nearer top. 8-inch coarse bed in center
10	2½	377½	Coarsely crystalline limestone. Fragments of large trilobite, *Isotelus gigas* deKay, and some small bryozoans
11	36	413½	Low cut exposure in swale of thin buff limestones which have irregular cherty beds near top
12	4	417½	Crystalline limestone in beds 6–10 inches thick. Bryozoans at top

SECTION 8a (*Continued*)

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
13	4½	421⅝	Buff crystalline limestone with brown sandstone in lower part
14	8⅜	430	Medium crystalline buff and gray limestones with elongate lenticular cherts. Sandstone partings extend through zone
15	6½	436⅜	Gray-to-buff finely crystalline limestone of thicker beds. Some thin sandstones and one 1.5-inch bed of chert, also scattered chert nodules
16	7⅞	444¼	Irregular beds of sandy limestone and brownish sandstone with scattered chert nodules
17	4⅞	449⅛	Rough beds of gray limestone with lenticular cherts. Some very thin sandstone partings
18	10 7/12	459¾	Gray-to-buff limestone in beds 2–4 inches thick, separated by laminated sandstones 0.5–2 inches thick. Rounded chert nodules scattered through limestones
19	2	461¾	Thin irregular beds of gray limestone with chert; separated by thin laminated sandy shale
20	5	466¾	Dense brown argillaceous limestone with 0.5-inch shale in middle of zone. Graptolites
21	4	470¾	Dense gray-to-brown shaly limestone with shale. Graptolites abundant. *Climacograptus spinifer* Ruedemann, *C. typicalis* Hall, *Dicranograptus nicholsoni longibasalis* Ruedemann and Decker, *Leptobolus insignis* Ruedemann
22	1 1/12	471⅞	Gray and brown banded shale and shaly limestone with graptolites in abundance as in zone above. Zones 21 and 22 correspond with base of Viola at Rock Crossing in Criner Hills, 83 feet above base in middle of Criner Hills, 100 feet above base on Highway 77, and 150 feet above base on West Spring Creek near Pooleville
23	1/12	472	Green and brown residual clay bed rests on uneven surface of Bromide formation of Simpson group
			Total thickness, 472 feet−45=427 feet

SECTION 9

P. A. Norris Ranch, Sec. 2, T.1 N., R.6 E.

Dip, 10°–15° NE.

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
1	85	85	Coarse-grained gray limestone constituting Fernvale phase. *Rhynchotrema capax* (Conrad)
2	6	91	Fine-grained light gray limestone
3	25	116	Fine-grained light gray limestone in beds 2–8 inches thick. *Dalmanella* sp., *Ctenodonta gibbosa* (Hall), *Cyrtodonta subangulata* (Hall)
4	26	142	Coarsely crystalline gray limestone in beds 2–8 inches thick. Many solution holes extend through beds. Crinoid stems near base of zone
5	25	167	Fine-grained light gray limestones in beds 4–8 inches thick. *Orthoceras sp.*, *Isotelus gigas* deKay
6	63	230	Upper part fine-grained light gray limestones with scattered calcite crystals. Exposed beds 2–8 inches thick, some parts soil covered. *Climacograptus typicalis* Hall, *Ctenodonta gibbosa* (Hall), *Cyrtodonta subangulata* (Hall), *Conularia trentonensis* Hall, *Westonoceras manitobense* Whiteaves
7	88	318	Fine-grained light gray limestone. *Ischadites* sp., small, *Receptaculites oweni* Hall, *Climacograptus typicalis* Hall,

SECTION 9 (*Continued*)

Zone No.	*Thickness in Feet* *Zone*	*Total*	*Description*
			Streptelasma profundum (Conrad), *Lingula philomela* Billings, *Platystrophia* sp., *Plectambonites sericeus* (Sowerby), *Rafinesquina alternata* (Emmons), *R. deltoidea* (Conrad), *Cyrtodonta subangulata* (Hall), *Prasopora* cf. *simulatrix* Ulrich, *Isotelus gigas* deKay, *Nileus vigilans* Meek and Worthen, *Thaleops ovatus* Conrad
8	34	352	Coarsely crystalline, porous, brownish limestones. *Prasopora simulatrix* Ulrich. Dip, 10° NE.
9	8	360	Coarse-grained, dark gray limestones, turn brown on weathering. *Sinuites cancellatus* (Hall), *Orthoceras* sp.
10	25	385	Coarse-grained-to-compact gray limestones. Upper part weathers brownish black
11	6	391	Thin-bedded gray to buff limestones. Main graptolite zone. *Climacograptus spinifer* Ruedemann, *C. typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Dicranograptis nicholsoni longibasalis* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Lasiograptus eucharis* (Hall), *Leptograptus flaccidus trentonensis* Ruedemann, *Mastigograptus gracillimus* (Lesquereux), *Dalmanella* sp., *Heberlella crispata* (Emmons), *Leptobolus insignis* Ruedemann, *Rafinesquina alternata* (Emmons), *R. alternata centristriata* Ruedemann, *Zygospira recurvirostris* (Hall), *Conularia* sp., *Oncoceras pupaeforme* Ruedemann, *Amphilichas trentonensis* (Conrad), *Ceraurus pleurexanthemus* Green, *Cryptolithus tessellatus* Green, *Gerasaphes ulrichana* Clarke, *Isotelus gigas* deKay, *Nileus vigilans* Meek and Worthen
			Total thickness, 391 feet

SECTION 10

ROCK CROSSING, CRINER HILLS, SEC. 35, T.5 S., R.1 E.

Dip, 45° SW.

About 75 feet of Viola are exposed below the dam on the northwest side of the bridge over Hickory Creek. The upper part next to the dam consists of thin, even beds of dark gray-to-brown tough limestone. The surface of many of these beds is made brownish black with the numerous graptolites which practically cover them. A small low anticline repeats the beds somewhat. Toward the base the rocks become more shaly and the number of species of graptolites increases materially. A 3-4-inch residual clay bed separates the base of the Viola here from the Bromide formation beneath it. This clay bed probably represents the erosion of about 83 feet of basal Viola, as in the section of the Viola in Sec. 27, T. 2 S., R.1 E., about 2 miles northwest, the graptolite zone which occurs at the base at Rock Crossing occurs 83 feet above the base.

In the upper zone below the dam: *Climacograptus typicalis* Hall, *Climacograptus typicalis crassimarginalis* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Glossograptus quadrimucronatus spinigerus* Lapworth.

In the lower zone, 0–20 feet above base of Viola: *Diplograptus* (*Amplexograptus*) *amplexicaulis* (Hall), *Climacograptus spinifer* Ruedemann, *C. typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *Cryptograptus insectiformis* Ruedemann, *Dicellograptus forchammeri flexuosus* Lapworth, *D. gurleyi* Lapworth, *Dicranograptus nicholsoni geniculatus* Ruedemann and Decker, *D. nicholsoni longibasalis* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Glossograptus ciliatus* Emmons, *G. quadrimucronatus* (Hall), *G. quadrimucronatus spinigerus* Lapworth, *Lasiograptus eucharis* (Hall), *Leptograptus flaccidus macer* Elles and Wood, *L. flaccidus trentonensis* Ruedemann, *Mastigograptus circinalis* Ruedemann, *M. gracillimus* (Lesquereux)

SECTION 11

MIDDLE OF CRINER HILLS, SEC. 27, T.5 S., R.1 E.

Dip, 45° W.

Measured, but details of description not worked out

Zone No.	Thickness in Feet Zone	Total	Description
1	80	80	Fernvale dark gray coarsely crystalline limestone. *Rhynchotrema capax* (Conrad)
2	532	612	Limestone, many zones have much chert. *Cryptolithus tessellatus* Green, *Isotelus gigas* deKay
3	213	825	Mostly even-bedded limestone much of which is distinctly banded
4	83	908	Limestone much like that in zone 3. Graptolite horizon at top of zone in which nearly every species and variety found at Rock Crossing was collected in short time writer was there, and *Corynoides curtus* Lapworth not found in region before. *Climacograptus eximius* Ruedemann, *C. spinifer* Ruedemann, *C. typicalis* Hall, *C. typicalis crassimarginalis* Ruedemann and Decker, *C. typicalis posterus* Ruedemann, *Corynoides curtus* Lapworth, *Dicellograptus forchammeri flexuosus* Lapworth, *D. gurleyi* Lapworth, *Dicranograptus nicholsoni geniculatus* Ruedemann and Decker, *Diplograptus vespertinus* Ruedemann, *Glossograptus quadrimucronatus spinigerus* Lapworth, *Lasiograptus* (*Thysanograptus*) *eucharis* (Hall), *Leptograptus flaccidus* Hall, *L. flaccidus macer* Elles and Wood, *L. flaccidus trentonensis* Ruedemann, *Mastigograptus circinalis ?* Ruedemann, *Cryptolithus tessellatus* Green

Total thickness, 908 feet

SECTION 12

NORTHWEST HILL SOUTH OF GOTEBO, SECS. 13, 14, T.6 N., R.16 W.

Dip, 16° NE. Strike, N.50° W.

Zone No.	Thickness in Feet Zone	Total	Description
1	59	59	Coarsely crystalline dark gray limestone in beds 1–3 feet thick. *Rhynchotrema capax* (Conrad), and several cephalopods characteristic of Fernvale which this zone represents
2	269	328	Dark chocolate, dense, regularly bedded, cherty limestones in beds 3–4 inches thick. Exposed in ravine and westward to base steeper part of hill
3	248	576	Dense, cherty, gray limestone with most beds about 4 inches thick though some 14 inches. *Cryptolithus tessellatus* Green and fragments of large trilobite probably *Isotelus gigas* deKay

Total thickness, 576 feet (paced)

SECTION 13

NORTH BRANCH MUDDY BOGGY CREEK, SEC. 29, T.1 S., R.12 E.

Dip, vertical. Strike, northeast

Zone No.	Thickness in Feet Zone	Total	Description
1	100	100	Gray-to-brown limestone in even beds with much chert A few 3–4 inch shales intercalated near top of zone
2	300	400	Alternating zones of thin and thick beds, latter coarsely crystalline, contain *Diplograptus recurrens* Ruedemann, especially near top of zone. (This species abundant also in upper Viola of Arbuckle mountain region)
3	100	500	Fine-grained thin beds at base with heavier beds more crystaline dark gray nearer top of zone with some fine shaly limestones intercalated. *Climacograptus eximius* Ruedemann, *C. spinifer* Ruedemann, *C. typicalis* Hall, *Dicellograptus for-*

SECTION 13 (*Continued*)

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
			chammeri flexuosus Lapworth, *Glossograptus quadrimucronatus spinigerus* Lapworth, *Leptograptus flaccidus macer* Elles and Wood, *Cryptolithus tessellatus* Green
4	50	550	Thin-bedded gray-to-brown limestone in beds 1–3 inches thick. Considerable chert and some shale partings

Total thickness, 550 feet (paced over top)

SECTION 14

GRANTS GAP, 2 MILES NORTHEAST OF STRINGTOWN, SEC. 3, T.1 S., R.12 E.

Dip, vertical. Strike, N. 55° E.

Zone No.	Thickness in Feet: Zone	Thickness in Feet: Total	Description
1	37	37	Thin even-bedded limestone. No Fernvale
2	165	202	Very cherty gray-to-buff limestone. Most beds 6–10 inches thick, some nearly 2 feet thick
3	167	369	Even-bedded limestone gray-to-brown in beds 1–6 inches thick. Poorly preserved graptolites in coarse limestone 15 feet below top of zone. Probably *Diplograptus recurrens* Ruedemann
4	83	452	Gray-to-chocolate thin-bedded limestone. Graptolites 10 and 30 feet above base and at top of zone. *Climacograptus typicalis* Hall, *Glossograptus quadrimucronatus* probably *spinigerus* Lapworth, because of size of forms 10th thecal spine not observed
5	50	502	Thin-bedded gray-to-chocolate limestone in beds 1–2.5 inches thick. Graptolites at top of zone. *Climacograptus spinifer* Ruedemann, *C. typicalis* Hall, *Dicellograptus forchammeri flexuosus* Lapworth

Total thickness, 502 feet

(Stringtown shale 210 feet thick is exposed below the Viola at this locality and Sylvan shale 167 feet thick above it.)

DISCUSSION OF SECTIONS AND TABLES

The section on West Spring Creek at the west end of the Arbuckle Mountains represents not only the greatest known thickness of the Viola of 929 feet, but also the purest limestone in its freedom from shale and sand. The rocks of this section are well exposed for study in the bottom of the creek channel for the entire thickness except in parts of zones 10 and 11.

The relatively small amount of clastic material in the Viola at the west end of the Arbuckle Mountains and at the northwest edge of the Wichita Mountains seems to indicate that deposition in these two areas was farther from shore than any other exposed parts of the Viola. More shale occurs in the graptolite zone at the south end of the Criner Hills than at the west end of the Arbuckle Mountains.

Also, the clastic materials increase eastward. On U. S. Highway 77 about 16 miles southeast of the West Spring Creek section, the shale in the Viola increases materially in a zone ranging from about 100 to 300 feet above the base. In the upper part of this zone the limestone beds have very uneven surfaces and shale fills the depressions in their

surfaces. Lower down in the main graptolite zone, though the beds become thicker and more even, shale partings occur and some of the beds are very argillaceous.

In the northeastern part of the mountains, on the P. A. Norris ranch and on Murray Lane south of Franks, many thin sandy beds occur at several horizons in the lower part of the Viola, and in the Atoka region the Viola limestone seems to grade into the Stringtown shales beneath. This seems to place the source of the clastics in the Viola east and northeast of the Arbuckle Mountains.

Erosion at the base of the Viola was very irregular. The most prolific graptolite zone, which occurs 150 feet above the base in West Spring Creek, 100 feet above on U. S. Highway 77, and 83–105 feet above in section 27 in the Criner Hills, occurs just above the base at Rock Crossing, showing an erosion of about 83 feet in only a little more than a mile. In the eastern part of the mountains at the northeast edge of Bromide and at the Witch Hole 4 miles southwest, the graptolite zone occurs 50–75 feet above the base and only the upper part of the zone remains in the sections south of Franks on Murray Lane and the P. A. Norris ranch, and this graptolite zone has been completely eroded away in the thin section on the Robertson ranch 3 miles south of Bromide and in the section 5 miles north of Bromide, where a limestone conglomerate occurs at the base of the Viola.

The light crystalline limestone characteristic of a large part of the Viola in the northeastern part of the mountains seems to be the type of this formation which is found in its subsurface development northward in Oklahoma (9, pp. 32–35; 11, pp. 968–970; 14, pp. 306–307) and in Kansas (16, p. 1541).

Table III lists the graptolites of the Viola and shows the distribution by zones in the sections. Several identifications have been made recently and the zones noted in several sections, and the new information secured in the Atoka region by the identification of the graptolites from that area is included. In this eastern extension of the Viola, seven species of graptolites have been found, which are characteristic of a corresponding horizon in the lower part of the formation in the Arbuckle Mountains, and *Diplograptus recurrens* Ruedemann occurs in the upper part of the formation in both regions.

A new collection was made on section 11 in the middle of the Criner Hills from a zone 83 to 105 feet above the base. Sixteen forms, including *Corynoides curtus* Lapworth, which had not been discovered previously in this region, have been identified from the beautifully preserved material in this zone. The recent measuring and collecting on the section has supplied the evidence that about 80 feet of lime-

stones below the graptolite horizon on this section are wanting in the Rock Crossing section 1.5 miles southeast, where the graptolite zone is separated from the Bromide formation beneath by only a 2–3-inch residual clay bed.

The list of other invertebrates in Table IV does not represent nearly all of the other invertebrates in the Viola, as some of the forms, especially among the bryozoa, brachiopods, and cephalopods have not been identified. However, the study of the forms identified by zones together with the graptolites has made it possible to recognize the parts of the Viola which are present in its numerous separate outcrops. The distribution of these invertebrates and the physical characteristics of the Viola supply significant evidence that this formation forms a good lithologic and stratigraphic unit, though some of its outcrops are widely separated, extending from the Atoka region on the east to the northwest edge of the Wichita Mountains south of Gotebo. It has also been recognized as widely distributed in the subsurface of central and northern Oklahoma and in Kansas, as already noted.

SUMMARY

The data secured for this paper were obtained by measuring 15 sections of the Viola limestone and by collecting from detailed zones in most of these sections. The measurements show a variation in thickness from 195 feet on the Robertson ranch, 2.5 miles south of Bromide at the east end of the mountains, to 929 feet on West Spring Creek at the west end. The Fernvale phase ranges in thickness from 24 (15, p. 22) to 80 or 90 feet, and this does not differ much from the measurements given by Bassler for central Tennessee, 10–76 feet (18, pp. 125–33). In three localities the Fernvale is absent, on Highway 77, 4 miles south of Davis; 2.5 miles west of Nebo Store; and in the region east and northeast of Atoka.

The conglomerate at the base of the Viola limestone in the northeast part of the mountains and the clay bed at the base at Rock Crossing in the Criner Hills mark a zone which is represented 100–150 feet above the base in sections along the southwest edge of the mountains on the West Branch of Sycamore Creek, U. S. Highway 77, and on West Spring Creek. The very fossiliferous zone near the southeast edge of Double Mound southwest of Lawrence Quarry is represented by a zone about the middle of the Viola, in the northeastern part of the mountains.

Several forms in the faunule developed locally at the southeast edge of Double Mound can be traced eastward into the middle part of the Viola where they are associated with other parts of the

Viola fauna in such a way as to give strong evidence of the unity of the Viola as a formation which is distributed in many separate outcrops. If any barriers existed in the Viola sea of this region, they must have been extremely local, or temporary, or of a nature such that graptolites, brachiopods, molluscans, and trilobites could get over or around them.

Two of the cephalopods, *Westonoceras* and *Whiteavesites*, connect the Viola with Baffin Island in the far north, with the Lake Winnipeg region and with southwestern Texas.

The most characteristic fossil of the Viola, *Cryptolithus tessellatus* Green, found elsewhere widespread in the Trenton, instead of being limited largely to the middle of the Viola, ranges practically from the base to the top and enters the coarsely crystalline Fernvale phase at the top. The interesting trilobite *Robergia athenia* Ulrich, which occurs in three of the sections of the Viola and commonly near the base 2 miles west of Nebo, seems to connect the Viola with the Athens shale of Alabama and the Ordovician of Sweden (10, p. 111).

The molluscoids and mollusks, as well as the graptolites, correlate parts of the Viola with the Normanskill, Trenton, Utica, Lorraine, and Richmond. Thus far only two graptolites have been found in common in the Viola and Stringtown shale and the evidence from the graptolites seems to indicate that most of the Viola is a little younger than the Stringtown shale. This relative age of the Viola with reference to the Stringtown shale has been proved recently by finding in the Atoka region 502 feet of Viola with its typical graptolite fauna included between the Stringtown shale beneath and the Sylvan shale above. Some of the Viola graptolites are found in the Ordovician of Canada and Texas, and in the Hartfell shales of Scotland and Ireland.

In the wonderfully rich graptolite phase of the fauna, 10 genera and 30 species and varieties, of which one species and three varieties are new, will be described in the Geological Society of America *Bulletin*, and two additional identifications are added to Table III.

The eastward extension of the Viola limestone and Sylvan shale into the region east and northeast of Atoka has been proved not only by their position and physical characteristics, but also by the presence in them of graptolite horizons which contain the same species as are found in corresponding horizons in the Viola and Sylvan of the Arbuckle Mountains. John Fitts assisted materially in extending these correlations eastward.

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VOL. 17, NO. 12 (DECEMBER, 1933), PP. 1436-1445, 1 FIG.

OIL AND OIL STRUCTURES IN OKLAHOMA-KANSAS ZINC-LEAD MINING FIELD[1]

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ABSTRACT

The Oklahoma-Kansas field of the Tri-State zinc and lead mining district is unique in that some of its mines produce oil as well as zinc and lead ore. The oil comes from above the mine workings, which range in depth from 150 to 400 feet from the surface. The original oil reservoirs are directly under the Pennsylvanian shale. The ore deposits are in rocks of Mississippian age. As the water is lowered, incident to mining operations, the oil enters the mine workings through fissures and shattered zones.

The importance of geologic structure and its relationship to oil and gas and ore deposits are evident. In each type, given a source of supply, the accumulation has been possible because favorable reservoirs were created and made accessible by structural deformation of the containing formations.

ACKNOWLEDGMENTS

This opportunity is taken to thank J. P. Lyden of Joplin, Missouri, who has worked with the writer in this district for nearly 6 years; M. D. Harbaugh of Miami, Oklahoma; and H. A. Buehler and H. S. McQueen of the Missouri Geological Survey for criticism and suggestions regarding this paper.

INTRODUCTION

The Oklahoma-Kansas (sometimes referred to as the Picher-Miami) field of the Tri-State zinc and lead mining district is unique in that some of its mines produce oil as well as zinc and lead ore. This field is the greatest zinc-producing area in the world as well as being an important producer of lead. The oil is of a dark residual variety and, instead of having to be pumped from great depths, comes from above into the mine workings, which range in depth from 150 to 400 feet from the surface. Furthermore, it is not "liquid gold," for it is a nuisance both in mining and milling operations. In a few mines it is sufficiently plentiful to be collected in sumps and sold locally for roofing purposes. There were some similar oil occurrences in mines of the older fields of the Tri-State district near Joplin, Webb City, and Granby, Missouri.

[1] Manuscript received, July 20, 1933.

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As mining proceeds with the lowering of the ground water, the oil drips from the roof and sides of the mines in certain areas, having worked its way downward through fissures and shattered zones from the original oil reservoirs, which were directly under the Pennsylvanian shale.

Numerous theories have been advanced regarding this exceptional association of oil and ore. Incidental to intensive study of the ore deposits of this region[3] during the past 7 years, these oil accumulations have been studied and, as would be expected, it has been found without exception that geologic structure definitely controls their localization.

GENERAL GEOLOGY

The general geology of the district is familiar to most students.

The topographic relief in most of the field is small, with elevations varying between 800 on the old meadows that cover most of the area and 975 feet above sea-level on the top of Blue Mound, an old erosional remnant. The basal beds of the Paleozoic sedimentary series, which varies in thickness from 1,200 feet to 2,000 feet, rest unconformably on the coarse, reddish granite so common as the basement formation throughout Missouri, Arkansas, and Oklahoma. This granite crops out in southeastern Missouri and in northeastern Oklahoma near Spavinaw. A generalized geologic section is here shown under Stratigraphy.

The Cherokee shale (Pennsylvanian) is the surface formation in most of the area. Its thickness here ranges up to 150 feet, except in depressions in the underlying formations, where it may exceed 200 feet. As the formations all dip northwest, the Cherokee feathers out near the eastern and southeastern edges of the field and thickens west and north, where it is the surface formation in a large area in Oklahoma and Kansas.

Southward from the mining field the Chester series, comprising limestone, sandstone, and shale, and the underlying Boone limestone, both of Mississippian age, successively become the surface formations. The Chester series is made up of the Carterville of Missouri, which is probably equivalent in part to the Batesville sandstone, the Fayetteville shale, and the Hindsville limestone of northern Arkansas. H. S. McQueen of the Missouri Geological Survey states that the Hindsville and Carterville give the same unusual sandy residues, in part oölitic. L. C. Snider, in *Oklahoma Geological Survey Bulletin 24*, Part I,

[3] Geo. M. Fowler and J. P. Lyden, "The Ore Deposits of the Tri-State District," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 102 (December, 1932), pp. 206–51. *Ibid., Tech. Pub. 446* (January, 1932), pp. 1–49.

1915, designated the strata between the top of the cherty Boone and the Fayetteville shale as Mayes limestone. This is an indefinite horizon. Snider's Mayes limestone should not be confused with the "black limestone" (cherty, very calcareous shale) of the same name, found in the subsurface in Oklahoma.

Variable thicknesses, ranging from a few inches to about 30 feet, of the Chester series, probably overlie the Boone in nearly all parts of the field, excepting in depressions, where it may exceed 100 feet. Drillers generally failed to differentiate the limestone in the bottom Chester series from the Boone.

Throughout the field, the products of chertification, in the form of chert, cotton rock, and tripoli, are present in most of the Boone. The Chester limestone contains grains and small pebbles of chert, of Boone age, and is silicified sporadically above some ore bodies by a later deposition of silica. Structural deformation of various types produced brecciation, which is common in all parts of the field.

Major unconformities are present between the Cherokee, Chester, and Boone formations, that between the Cherokee and the Chester being greatest. Representatives of the Morrow group and the earliest (Pottsville) Pennsylvanian are missing in the Oklahoma-Kansas mining field.

STRATIGRAPHY

A generalized geologic section of the formations in the Tri-State district is shown in Table I.

TABLE I

STRATIGRAPHIC SECTION, TRI-STATE DISTRICT

System *Series*	*Character of Formations*	*Thickness in Feet*
Carboniferous		
Pennsylvanian	Shale and sandstone (Cherokee) This formation covers most of the surface in the vicinity of Baxter Springs, Kansas, and Picher and Commerce, Oklahoma. It is largely absent, except in sink holes, in the old fields of Missouri and Kansas	0– 250
Mississippian	Chester series—limestone, sandstone, and shale. Occurs as outliers in sink holes in all parts of district. In extreme southern part, between Miami and Lincolnville, Oklahoma, and southward, it is exposed for many square miles. Particularly good limestone exposure along highway on small hill 3 miles due east of Miami	0– 50
	Boone formation—limestone, dolomite, and chert—originally all limestone	200– 400
	Shale (Northview or Chattanooga). Absent in most of district. In drill holes few miles south of Joplin shale is 1–6 feet thick. Formation gradually thickens south and	0– 10

	east. Some geologists place this shale in Devonian	
Ordovician	Largely dolomite	700– 1,000
Cambrian	Dolomite and sandstone. In well No. 6 at Carthage, Missouri, there is 590 feet of dolomite and sandstone between base of Gunter (Ordovician) and top of pre-Cambrian, according to McQueen. He reports it absent in Bird Dog well log in Table III. This and other formations are described in his insoluble residue report in 1931 Biennial Report of the Missouri Bureau of Geology and Mines	0– 800
Pre-Cambrian and probably more recent	Granite and other igneous rock	

The writer's study of the geology and ore deposits has revealed the Boone formation to be separable into several beds which are nearly uniform in thickness and characteristics throughout the district. This detailed stratigraphic section is shown in Table II.

This stratigraphic section is the result of more than 3 years' intensive study of the Boone formation. Partial chertification of the limestone made it impossible to utilize the usual methods. Horizon markers were necessary in order to determine the detailed and general structural geology. They were established solely on lithologic evidence. Their determination is made from churn-drill cuttings, road cuts, cliffs, and underground workings. The method is being extended throughout the district with marked success as work progresses.

The chert nodules and concretions so characteristic in some of the limestone strata, particularly beds M and K, are due to infiltration of silicic acid solutions. Stylolite partings and similar channelways were particularly favorable points of ingress.

Designation of the beds in alphabetical order is for convenience. Beds A, and S to Z have been disregarded until more is known regarding their lithologic characteristics. They are probably barren and are inaccessible in most mines. The important ore beds are near the middle of the series and are accessible for study in many miles of underground workings.

TABLE II

STRATIGRAPHIC SECTION OF BOONE FORMATION

Bed	*Thickness, Feet*	*Characteristics*
B	0–125 (depending on erosion)	Gray and brown limestone and dolomite. Probably includes variable thickness of Carterville, Chester series
C	25– 32	Gray and brown limestone and dolomite. Blue, brown, and white chert (blue chert horizon near base)
D	18– 22	Nearly white limestone, dolomite, and chert. "Cotton rock" horizon

E	5– 8	Generally coarse, "sandy" dolomite or chert. Important ore bed in some mines. Important source of galena
F	12– 15	Limestone or chert. Generally barren
G	8– 13	Important ore horizon in some mines near Picher. Ore occurrences in this and H bed are generally similar, but this bed is richer. G and H in places mined as one bed
H	15– 20	Ore horizon in some mines. Thin-bedded limestone or cherty bands 2–5 inches thick, with the ore gradually replacing thin (0.25–2 inches) favorable strata. This stratified mineralization almost invariably occurs with banded galena above sphalerite. In places ore is in 8–10 feet stratum directly above J. Nodules generally absent in beds F, G, and H
J	4– 8	Barren limestone or chert. Mineralized only in areas of intense shattering. Also occurs as soft, greenish, calcareous stratum. Bottom of Warsaw formation
K	8– 12	Top of Keokuk formation. Important ore bed. Comprises rounded nodules 5–9 inches in diameter in upper part of bed with long, larger nodules in lower part. Ore generally confined to upper two-thirds of bed. Short Greek oölite horizon is indefinite. It is 5–8 feet thick and is found from the top of K bed to the bottom of L bed
L	26– 30	Massive limestone or chert. Contains ore in zones of intense deformation. In places contains 5-foot stratum of oölite
M	19– 22	One of most important ore beds of Oklahoma-Kansas area. Where metamorphosed, definite nodules 4–12 inches in diameter occur throughout bed. In many places large nodules (6–12 inches thick by 2–5 feet in diameter) at bottom of bed. This bed as mined in different parts of Oklahoma-Kansas area varies in thickness from 5 to 22 feet. Bottom 12 feet most productive horizon
N	20– 25	Massive limestone, dolomite or chert with very few large (1 foot thick by 5–15 feet diameter) nodules. In some mines "porcelain" stratum 1 foot thick found 6–8 feet from top of bed. Contains ore horizon 8 feet thick near center of bed in a few mines
O*	8– 9	Important ore bed in a few mines. Round, flat nodules (2–4 inches by 3–6 feet) embedded with cherty bands 1–4 inches thick. In some mines contains interbedded layers of nearly pure galena or sphalerite, or both, varying in thickness from fraction of inch to several inches. These sheets of ore continuous in large areas. Such mineralization comprises "sheet ground" mines in old Missouri fields. Southern part of See-Sah Mine, near Cardin, Oklahoma, is in this bed and is in "sheet ground" formation
P*	8– 11	Large flat chert nodules interbedded in chert, generally barren, but in places mineralized with beds O, P, and Q, making ore horizon 30–38 feet thick
Q*	17– 18	Limestone and chert, generally massive. Only relatively few churn-drill holes have reached depths greater than 50 feet below Q bed
R	55±	Top of Reed Springs formation. Largely dense limestone, dolomite or gray and blue chert, with chert nodules

* The Grand Falls chert horizon described by Smith and Siebenthal in *U. S. Geological Survey Atlas 148, Joplin District Folio*, 1907, is found only in, or related to, zones of deformation. In undisturbed areas it is limestone. It falls within the range of beds O, P, and Q. Smith and Siebenthal give it a thickness of 15–120 feet and state "it lies about 100 feet below the Short Creek oölite." The Short Creek oölite is found sporadically from the top of K bed to the bottom of L bed, a vertical range of 40 feet.

Table III shows the formations below the Boone according to a correlation by H. S. McQueen, assistant State Geologist of Missouri, made from drill cuttings from a well drilled in 1930 at the Commerce

Mining and Royalty Company's Bird Dog Mine in the SE. ¼, SE. ¼, Sec. 13, T. 29 N., R. 22 E., near Picher, Oklahoma.

TABLE III

FORMATIONS BELOW BOONE

Correlated by H. S. McQueen

System *Formation*	*Thickness, Feet*	*Depth from Surface, Feet*	*Characteristics*
Pennsylvanian	100	0–100	Shale
Mississippian	315	100–415	Chert, limestone, and dolomite
Ordovician	5	415–420	Brown, finely crystalline dolomite; sand grains; brown, white, and sandy chert; some dark green shale and pyrite
	5	420–425	Gray, finely crystalline dolomite; 40 per cent insoluble, sand grains, chert, and shale
	10	425–435	Light brownish gray, fine-grained sandy dolomite; dark brown quartzose and glassy chert, with associated fragments of sphalerite; also gray white chert
Cotter	25	435–460	Dense gray-to-brownish gray dolomite; fine-grained sand; white, gray, and brown chert; some pyrite and few fragments of sphalerite
	70	460–530	Gray, dense, fine-grained dolomite. Insoluble residues comparatively small, 5–35 per cent; considerable sand, 495–520 feet
	320	530–850	Dolomite similar to above, with gray and blue-gray chert oölitic and banded to 585 feet; below that depth, brown chert dominant. "Shines" of zinc at 680 feet
Jefferson City	45	850–895	Dark brownish or bluish gray, finely crystalline dolomite. Insoluble residues small excepting 850–855 feet; 40 per cent brown, sandy, and quartzose chert
Roubidoux	115	895–1,010	Light gray, fine-grained dolomite; sandy in basal part, with some chert
Gasconade	150	1,010–1,160	Gray and bluish gray finely crystalline dolomite; insoluble residues up to 50 per cent contain chert
Van Buren	20	1,160–1,180	Blue-gray dolomite; insoluble residues contain chert; also sand and fragments of porphyry at 1,180 feet
Gunter	5	1,180–1,185	Dark gray finely crystalline sandy dolomite; insoluble residues 5 per cent contains: sand, fine, generally rounded and frosted grains; with chert white and sandy; also granite, bluish gray and red, both types kaolinized; pyrite
Pre-Cambrian: granite and possibly porphyry	10	1,185–1,195	Granite, red and bluish gray; latter finer-grained and chloritic and possibly a rhyolite. Both contain pyrite and hornblende
	11	1,195–1,206	Granite, red, very coarse-grained, with fragments of bluish gray, like above. Pyrite

The subsurface structure of the Oklahoma-Kansas mining field may be likened to that of an oil field which comprises domes, basins, anticlines, synclines, and allied flexures. Nearly all these structures are small, but they differ greatly in both vertical and lateral dimensions.

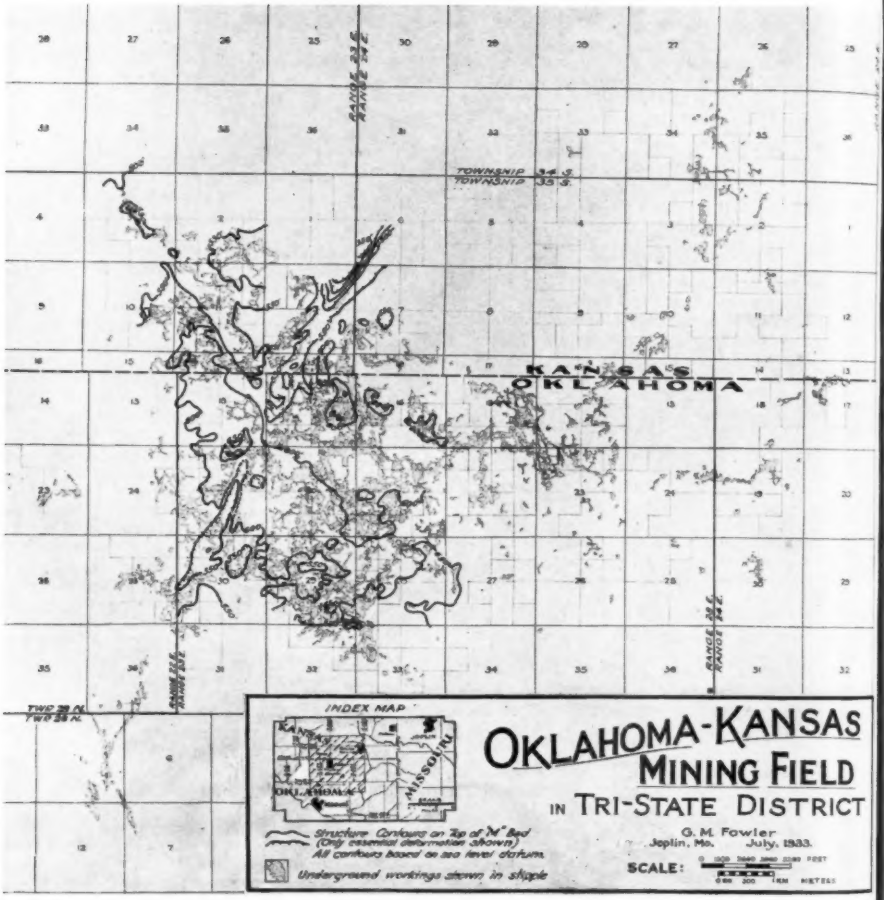
KANSAS
OKLAHOMA
INDEX MAP
OKLAHOMA-KANSAS
MINING FIELD
IN TRI-STATE DISTRICT
G. M. Fowler
Joplin, Mo. July, 1933.
SCALE:
Structure Contours on Top of "M" Bed
(Only essential deformation shown)
All contours based on sea level datum.
Underground workings shown in stipple

FIG. 1.

Their areas range from the fraction of an acre to several acres. The vertical deformation of some exceeds 100 feet. Also, there are fissure or shear zones which range in width from a few inches to several hundred feet, and in length from a few feet to more than a mile.

The accompanying generalized structural map (Fig. 1) of the field shows the principal domes. This map is contoured on a major ore-bearing bed in the Boone formation. Oil in various quantities was found in nearly all of these domes, and natural gas, in small quantities, was present in a few of them. The oil reservoirs are confined largely to the porous brecciated and sheared zones in the chert, particularly those parts of such zones directly under the shale. The largest and most prolific of these oil pools is located on the Federal Gordon lease in the SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 18, T. 29 N., R. 23 E., 1 mile north of Cardin, Oklahoma. Large accumulations of oil were found in some of the shear zones west of Commerce, Oklahoma, and were a serious detriment in the mining of these ore bodies.

The volume of oil per cubic unit was greatest in the sharply flexed domes where the overlying shale was subjected to the most intense deformation and where the greatest porosity necessarily developed in the containing formation. The volume decreases in proportion to the lessened intensity of deformation. In flat or slightly domed areas and in basins there is little or no oil unless shear zones traverse the areas; in which case the oil also varies in proportion to the degree of deformation and consequent brecciation. Where structural conditions are favorable for oil accumulation, the Chester limestone, as well as the Boone, is generally oil bearing. Oil is now found in mine workings several hundred feet below the surface, and is particularly noticeable in fissures exposed in the roofs of many of them.

ADJACENT OIL FIELDS

Commercial oil and gas has long been produced in Craig County, Oklahoma, and Labette County, Kansas, just west and northwest of the mining field and within 15 miles of it. This production is mostly from sandstone lenses and horizons in the Cherokee, although some of it may be from the underlying Boone. As the Cherokee thins toward the east and southeast the oil and gas become more scarce. Hence, it is easy to see that the residual accumulations in the mining field are exactly what would be expected.

It may be of interest to note that the writer has always found silicified (chertified) limestone in, or contiguous to, areas of deformation, the silica having been introduced through channelways formed during the periods of deformation. Perhaps the siliceous limestones

found in the Arbuckle formation in some of the southeastern Kansas and northeastern Oklahoma oil fields are similar in origin. Chertified limestone of secondary origin, and definitely related to zones of deformation, is found in many limestones in different parts of the United States.

OIL SEEPAGES

The mining operations destroyed a few oil seepages that were surface phenomena in this area. The largest was within the present townsite of Cardin, Oklahoma, on the banks of Tar Creek, so named because of these seepages. Other springs were found along this stream, which flows south through the field. The oil accumulations which were the sources of these seepages were due to the structural features similar to those described in the preceding paragraphs and, of course, the origin of the oil was similar. It reached the surface through shear or fissure zones in the Cherokee shale, although, compared with the great number occurring in the formations below, very few of these shear zones penetrated the shale.

ORIGIN OF OIL

A sample of Cherokee shale from a shaft in the northwest corner of the Southside lease near Commerce, Oklahoma, was submitted to F. E. Gregory of the research department of the Eagle-Picher Mining and Smelting Company for distillation tests. His tests gave the extractions of hydrocarbons shown in Table IV, suggesting the Cherokee as the source of the oil.

TABLE IV

ANALYSIS OF CHEROKEE SHALE

By F. E. Gregory

500 grams of shale dried at 40°C. for 48 hours, were distilled through the following temperature ranges:

Temperature °C.	*Time (Minutes)*	*Products*
80– 90	30	CH_4
90–100	30	CH_4; C_6H_6; $C_6H_5 \cdot CH_3$ H_2O; C_2H_6; CO_2; CO
100–115	30	CH_4; C_6H_6; $C_6H_5 \cdot CH_3$ H_2O; C_2H_6; CO_2; CO
115–140	30	NH_3; NH_4OH; H_2S $C_{10}H_8$; CH_4; C_6H_6; NH_3 Other hydrocarbon gases not identified
140–180	30	CH_4; C_6H_6; $C_6H_5 \cdot CH_3$ H_2O; C_2H_6; CO_2; CO NH_3 Some of the phenol group not identified
180–220	30	Phenols, heavy tar not identified, and naphthalene
220–300	30	Phenols, tar, and naphthalene

The residue contained a large part of fixed carbon.

The volume of CH_4, C_6H_6, CO_2, CO given off occupied a volume of 642 cubic centimeters at standard conditions. Of this 311 cubic centimeters was CO_2. By difference the volume of CH_4 and C_6H_6, and kindred products liberated was 331 cubic centimeters.

OIL AND ORE RESERVOIRS

The opportunity to study ore deposits together with oil and gas accumulations in the same area emphasizes the importance of geologic structure and its obvious relationship to both types of deposit. In each type, given a source of supply, the accumulation has been possible because favorable reservoirs were created and made accessible by structural deformation of the containing formations. Incidentally, the contouring of a convenient horizon in the ore-bearing formation at 5-foot intervals is the method the writer has used in great detail in determining the structural features of importance in the search for ore. The oil reservoirs are found in the traps beneath the shale, ordinarily at the tops of the domes; the ore reservoirs are found in the parts of domes, synclines, or related structures where the stresses were relieved.

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GULF COAST GEOSYNCLINE[1]

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Houston, Texas

ABSTRACT

The presence of a geosyncline along the Gulf Coast of Texas and Louisiana is indicated both by geologic and geophysical data. The formations which are exposed at the surface or in drilling are known in general to dip gulfward. The known stratigraphic thickness of formations plus shrewd extrapolation below reach of the drill indicate that the depth to the basement at Houston is greater than 20,000 feet, at Jennings, Louisiana, greater than 25,000 feet, and south of New Orleans greater than 30,000 feet. Seismic prospecting indicates that the basement certainly is deeper than 15,000 feet and, less definitely, that it is deeper than 20,000 feet. The torsion-balance data indicate that the base of the salt core of the salt domes lies at a depth of 17,000–20,000+ feet in the Houston district. The depth of the Gulf of Mexico in the Sigsbee Deep is 12,500, and throughout most of its area, is less than 10,000 feet. Tne thickness of the post-Lower Cretaceous sediments in the central part of the Gulf of Mexico presumably is not more than a very few thousand feet. The basement of the post-Lower Cretaceous beds in the Gulf Coast must be warped down at least 5,000 feet at Houston and at least 15,000 feet in the area south of New Orleans. A regional trough of gravity minimum lies axially along the Gulf Coast. Calculations suggest that it is best explained by a geosyncline on the basement plus a progressive character of the basement from granitic under the land to basaltic under the Gulf of Mexico. A study of the depression of the basement to compensate sedimentation suggests that the trough line of the geosyncline should lie nearly at the present coast line; and that is approximately the position which the gravitational calculations indicated for the actual position of the trough line. Although isostatically negative, the area has been one of continued subsidence; and the rate of subsidence seems to have kept even pace with the rate of sedimentation.

The purpose of the writers of this paper is to emphasize the fact of the probable presence of a geosyncline in the Gulf Coast area of Texas and Louisiana. The thought is not novel with the writers: it has evolved gradually during the past decade; more particularly during the past 5 years as the drill, the seismic method, and the torsion-balance method have given definite data in regard to the great thickness of the unconsolidated sedimentary beds in the Gulf Coast. Presumably some geologist technically has priority in the literature for suggestion of the thought; but actually it is impossible to ascribe priority to any one geologist. The fact of the probable presence of the Gulf Coast geosyncline is not widely realized. Howe calls attention, for example, to the fact that recent standard textbooks speak as if the thickness of the Tertiary beds in the Gulf Coast were only a few thou-

[1] Read before the Association at the Houston meeting, March 23, 1933. Manuscript received, August 28, 1933.

[2] Consulting geologist and geophysicist, Petroleum Building.

sand feet. The purpose of these writers is to call more general attention to the fact that in the Gulf Coast of Texas and Louisiana, we do seem to have a geosyncline comparable with the Appalachian geosyncline.

The evidence for the presence of the geosyncline is stratigraphic and geophysical.

The stratigraphic argument for the existence of the geosyncline is: (1) that the Upper Cretaceous and Tertiary beds dip gulfward; (2) that the Tertiary beds, particularly, thicken greatly gulfward; (3) that the stratigraphic thickness of the Tertiary and Upper Cretaceous beds in the Gulf Coast must be of the general order of magnitude of 20,000 feet at Houston and 30,000 feet south of New Orleans; (4) that the depth of the deepest part of the Gulf of Mexico is 12,500 feet and the depth of most of the Gulf of Mexico is less than 10,000 feet; (5) that the thickness of the Upper Cretaceous-Tertiary sedimentary deposits over the great depths of the center of the Gulf of Mexico presumably must be less than 1/10 the thickness of the corresponding beds in the Gulf Coast; and (6) that in the Gulf Coast, therefore, the basement of the Upper Cretaceous-Tertiary beds must be downwarped 6,000 to 16,000 feet in reference to the depth of that basement under the Sigsbee Deep, and 8,000 to 18,000 in reference to the depth of that basement throughout much of the great depths of the Gulf of Mexico.

TABLE I

NORMAL THICKNESS OF FORMATIONS IN VICINITY OF HOUSTON

(After Teas, and McCarter and O'Bannon)

		Feet	*Depth to Base*
Recent; Beaumont and Lissie	Pleistocene	1,800	1,800
Goliad	Pliocene	500	2,300
Lagarto and Oakville	Plio-Miocene	2,800	5,100
Catahoula	Miocene (Oligocene?)	500	5,600
Middle Oligocene	Oligocene	1,400	7,000
Frio	Oligocene	1,800	8,600
Vicksburg	Oligocene	1,200	9,800
Jackson	Eocene	1,500	11,300
Claiborne			
Yegua	Eocene	2,000	13,300
Cook Mountain	Eocene	600	13,900
Mount Selman	Eocene	1,000	14,900
Wilcox (penetrated only farther inland)	Eocene	2,500+	17,400+
Midway (penetrated only very much farther inland)	Eocene	?	
Navarro (trace found on South Liberty dome)	Upper Cretaceous	?	

The general gulfward dip of the Upper Cretaceous beds, the gulfward dip of the Tertiary beds, and the general gulfward thickening of the Tertiary formations are commonly known. The respective thicknesses of the Tertiary formations at the outcrop range from a few

hundred to a thousand feet. The corresponding thicknesses in the Gulf Coast in general range from a thousand or more to several thousand feet. The normal thickness of the formations in the vicinity of Houston is given in Table I.

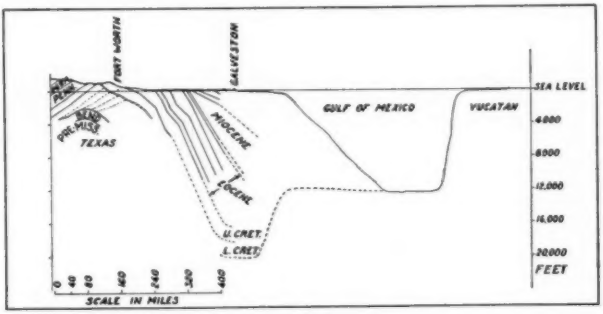
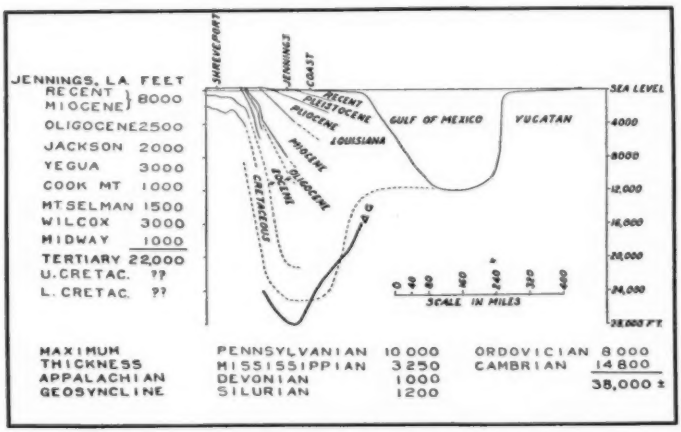


FIG. 1.—Geologic sections.

A. Fort Worth-Galveston-Sigsbee Deep.



B. Sabine uplift-Jennings-Sigsbee Deep.

The data for the thickness of formations above the Jackson are obtained directly from wells away from shallow salt domes. The deepest well in this general area is drilling at a depth greater than 9,500 feet. The thickness of the Eocene formations is obtained from wells on the flanks of the shallow salt domes, on which those formations have been greatly uplifted.

At Roanoke, Louisiana, the normal depth to the top of the Oligocene is greater than 7,800 feet. Farther east, in the Morgan City district, the normal depth to the top of the Miocene probably is 6,000 feet. The upper formations, therefore, thicken greatly eastward from the Houston area to the area of the Mississippi delta.

A stratigraphic thickness of the Quaternary, Tertiary, and Upper Cretaceous and a depth to the basement, in the Houston area, of at least 20,000 feet, therefore, is somewhat definitely indicated by the known stratigraphic data. The thickness of the formations down to the base of the Claiborne (Eocene) is known to be approximately 15,000 feet. There is no geologic reason to surmise that the Wilcox and Midway are not present and do not have at least a considerable percentage of their thickness where they are last penetrated farther up the dip. The depth to the base of the Tertiary presumably, therefore, is at least 18,000 feet and may be 20,000 feet. What seems to be uppermost Navarro chalk has been encountered caught in the cap of the South Liberty salt dome (Liberty County, Texas). The upper Cretaceous formations seem to have been deposited in a sea which extended northward from the Gulf of Mexico across the Gulf Coast into the interior of Texas and Louisiana. The thickness of the Upper Cretaceous can only be guessed; and at a guess, it must be at least 1,500 feet. It is risky to surmise either that any Lower Cretaceous is present in this area or that it is not present. There is no reason known why it can not be present. The depth to the basement in the Houston area, therefore, must be at least 20,000 feet, more probably is at least 22,000 feet, and may be as much as 25,000 feet.

A depth to the basement of more than 25,000 feet in the Jennings-Roanoke district, and of more than 30,000 feet in the area south of New Orleans, is indicated fairly definitely by the stratigraphic data, for the known thickness of the post-Oligocene section is at least 2,200 feet thicker at Roanoke, Louisiana, than it is in the Houston area, and the post-Miocene section in the Morgan City area is at least 2,500 feet thicker than it is at Roanoke; and presumably the lower formations also thicken eastward.

Data from the geophysical prospecting in the Gulf Coast indicate a depth to the basement of 15,000–20,000 feet or more in the Houston-Jennings area. In the reflection seismic method of mapping structure, key beds at depths of 12,000–15,000 feet are being used; and the velocity of transmission of the seismic waves indicates that the beds to those depths are unconsolidated. Some of the senior writer's seismic geophysicist colleagues believe that they have recorded very few reflections from depths of 20,000 feet; these somewhat uncertain deter-

minations indicate a depth of 20,000 feet to the basement, or at least to massive high-speed formations such as limestones, which might form a basement under the unconsolidated or relatively unconsolidated overlying beds. Calculations in regard to the probable form of the salt cores which produce the observed gravity minima, indicate that the base of the salt core in the Houston district lies at depths of 15,000 to 20,000 feet. The data indicate definitely that the base can not lie at a shallower depth than 15,000 feet, but the data and the calculations which the writer used were not exact enough to show that the depth to the base of the salt core could not be as much as 25,000 feet.

A geosynclinal downwarp of the basement must be present in the Texas-Louisiana Gulf Coast, if the depth to the basement ranges from 20,000+ feet in the Houston district to 30,000+ feet in the area south of New Orleans. The southward plunge of the formations indicates the northern flank of the geosyncline. The southern flank of the geosyncline is indicated by the extreme depth of the Gulf of Mexico in reference to the seemingly indicated depth of the basement in the Gulf Coast. The depth of the Sigsbee Deep is 12,500 feet; most of the rest of the floor of the Gulf of Mexico does not reach a depth of 10,000 feet. The thickness of the Quaternary-Tertiary-Cretaceous sedimentary deposits is as yet uncertain. The slope of the continental shelf seems presumably to be a crude measure of the decrease of sedimentation gulfward and to indicate only slight sedimentation in the central parts of the Gulf of Mexico. It is possible that the Sigsbee Deep is partly the effect of local deformation in connection with the Yucatan orogenic movements and that the crest of the basement lies north of the Sigsbee Deep. We may surmise, therefore, that the depth to the basement over the central part of the Gulf of Mexico is not greater than 15,000 feet (12,500+2,500) and presumably may not be more than 12,000 feet. The basement, therefore, must be warped down northward to an extent of 5,000+ feet and more probably 8,000+ feet at Houston and several thousand feet more at some place between Houston and the edge of the continental shelf; and to an extent of 15,000 to 18,000 feet in the area south of New Orleans.

The regional variation of gravity suggests the presence of a geosyncline on the basement of the Texas-Louisiana Gulf Coast.

An areally extensive trough of gravity minimum lies axially along the Texas-Louisiana Gulf Coast. It is shown by the map of the regional variation of gravity in southern United States and in the northern half of the Gulf of Mexico (Fig. 2). The variation of gravity of the map is based primarily on the pendulum observations of the

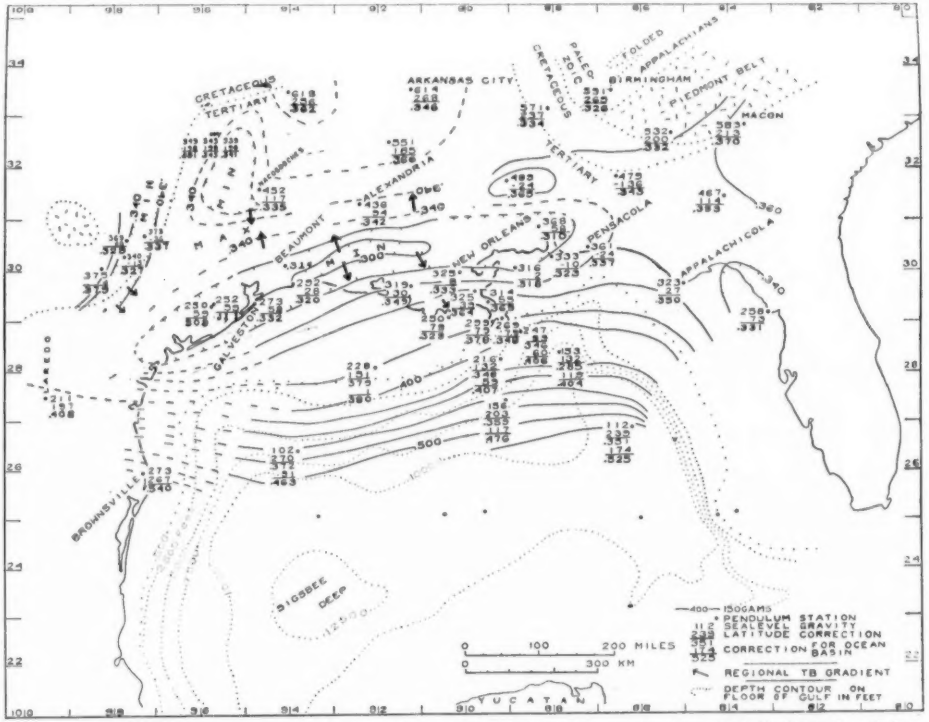


FIG. 2.—Map showing variation of gravity in southern United States and adjacent Gulf of Mexico. Values of gravity are reduced to sea-level and to latitude of Orange, Texas. Land pendulum observations by United States Coast and Geodetic Survey. Pendulum observations in Gulf of Mexico by Vening Meinesz. Arrows give qualitatively general effect shown by torsion-balance surveys. Of series of numbers at each pendulum station: upper is sea-level value of gravity; second is correction for latitude; third is sea-level value of gravity corrected to latitude of Orange, Texas; fourth (on gulf stations only) is correction for slope of continental shelf; and fifth is resulting sea-level value of gravity corrected to latitude of Orange and as if land extended out across Gulf of Mexico.

United States Coast and Geodetic Survey and of Vening Meinesz' traverse of the Gulf of Mexico in a submarine, but these are supplemented by an intimate knowledge of the extensive torsion-balance surveys in Texas and Louisiana. The sea-level value of gravity for each pendulum station has been corrected to the latitude of Orange, Texas, in order to eliminate the obscuring effect of the latitudinal variation of gravity which has no relation to the structure of the earth's crust. The latitude of Orange has no special advantage for this problem over any other latitude. The first working edition of this map was made in an effort to extend the gravity picture of an extensive torsion-balance survey by means of the pendulum observations; and the only place in which the torsion-balance survey corresponded with a pendulum station was at Orange. The values of gravity at the stations in the Gulf of Mexico have been corrected also for the effect of the slope of the continental shelf. The gulfward slope of the contact between the water above and the sediments below is sufficient to produce a considerable gravitational effect which has no relation to the structure of the earth's crust. The density of the sediments of the continental shelf was assumed to be 1.5. The surface of the continental shelf was assumed to be composed of a succession of a very few plane surfaces and each of them was assumed to be infinite in extent. The gradient which should be produced by the plane slope of each zone of the continental shelf was calculated by the common formula for an infinite horizontal slab with sloping front and multiplied by the width of the zone to give the value of Δg across the zone. The sum of the Δg's for the successive zones from the shore out to the pendulum station was taken as the correction. It presumably is approximately correct. The variation of the resulting values of gravity, which are the bases of the isogams of Figure 2, is assumed to be the effect of the structure of the earth's crust.

Three different sets of subsurface conditions might produce an axial gravity minimum along the Gulf Coast: (1) a geosyncline on the surface of a basement homogeneous in character horizontally from the center of the Gulf of Mexico to the center of the continent; (2) a gulfward regional dip of the surface of the basement in the Gulf Coast area plus a progressive change in the character of the basement from a granitic composition under the continent to a basaltic composition under the center of the Gulf of Mexico; and (3) a geosyncline on the basement in the Gulf Coast plus that progressive gulfward change in the character of the basement (Fig. 3). A fourth condition, that the minimum is wholly a salt effect, was suggested by the senior writer,[3] but does not now seem plausible.

The third hypothesis is suggested by tentative, qualitatively quantitative calculations as being more probably the correct one. In the calculations, a series of assumed cross sections of the upper part of the earth's crust from the Sabine uplift to the center of the Gulf of Mexico were drawn (Figs. 3 A, B, C). The theoretical profile of gravity which would be produced by each was calculated and compared with the observed gravity-profile. The following assumptions in regard to the upper part of the earth's crust were used.

The upper 70 kilometers of the earth's crust consist of (1) the mantle of sediments; (2) an underlying granitic basement, with its base at a depth of 10 kilometers; and (3) a substratum 60 kilometers thick.

The four assumptions in regard to the character of the substratum are: (1) no change in density, that is, the substratum might be composed of granite or basalt; (2) gradation from a specific gravity of 2.6 at the landward end to a specific gravity of 3.3 at the gulfward end, that is, a gradation from granitic character at the landward end to basaltic character at the gulfward end; (3) gradation from a specific gravity of 2.6 at the landward end to a specific gravity of 3.1 at the gulfward end; and (4) a vertical gradation at the landward end from a specific gravity of 2.6 at the top to 3.3 at the bottom and simultaneously a horizontal gradation to 3.3 at the gulfward end.

For each of those assumptions, various assumed conformations of the top of the granitic basement were used. The mantle of water above the continental shelf was not taken into account for the reason that its effect had already been eliminated.

The calculations of the effect of the form of the surface of the basement were made in part by the writer's graphical method and in part by the ordinary analytical formula for the gradient produced by an infinite step-block with a sloping front. The calculations of the effect of the variation of the specific gravity of the basement were made by the following formula which was derived for the gradient which would be produced by a linear variation in the density of a horizontal bed of uniform thickness.

$$U_{zz}=2Kk\{z_2[\tan^{-1}(x_2/z_2)-\tan^{-1}(x_1/z_2)]-z_1[\tan^{-1}(x_2/z_1)-\tan^{-1}(x_1/z_1)]\}$$

where K = gravitational constant; k = change in density of the bed per horizontal centimeter; and the dimensions of the block are given by the rectangular coördinates (x_1, x_2), $y=\pm\infty$, and (z_1, z_2). In all these calculations, the gradient was obtained for enough stations to

[3] D. C. Barton, "Torsion Balance Surveys in Southwest Louisiana and Southeast Texas," *Trans. Amer. Geophys. Union*, 13th annual meeting (1932), pp. 40–42.

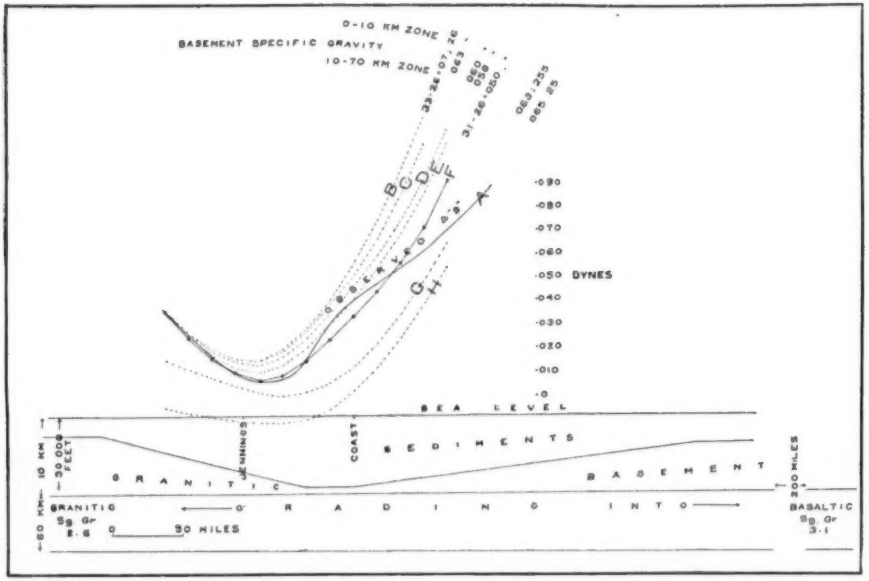


FIG. 3.—Calculation of basement which will produce observed regional profile of gravity across Gulf Coast.

A. Hypothesis of geosyncline plus horizontal gradation in character of sub-stratum. Below—assumed cross section of upper 70 kilometers of earth's crust. Above—A = observed profile of gravity; *B–H* = calculated gravity profiles produced by that cross section under several assumptions in regard to density situation.

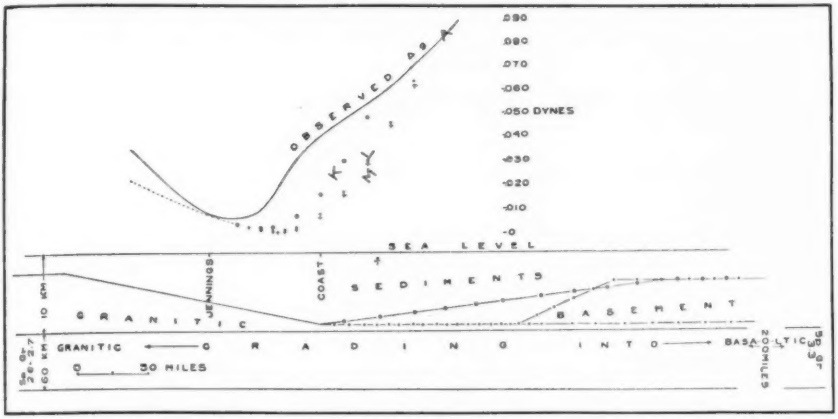
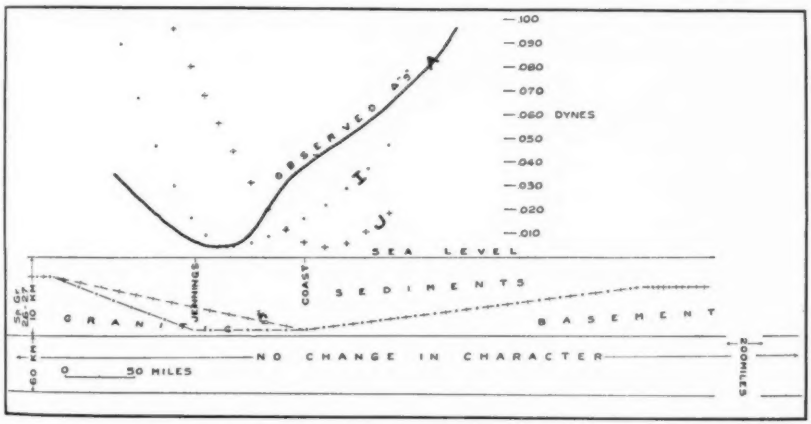


FIG. 3.—Calculation of basement which will produce observed regional profile of gravity across Gulf Coast.

B. Hypothesis of geosyncline plus no horizontal change in character of substratum. Below—assumed cross section of upper 70 kilometers of earth's crust. Above—*A* = observed profile of gravity and calculated profiles of gravity corresponding with cross sections below.



C. Gulfward slope of basement plus horizontal gulfward gradation in character of basement (*M*); also geosyncline plus horizontal gradation in character of basement (*K* and *L*).

give the gradient profile, and Δg was then obtained by numerical integration. This indirect method of calculation of Δg was used for the reason that it seemed simpler to use the familiar gradient formulae which are in constant use in interpretation of torsion-balance surveys than to look up or derive the corresponding formulae for Δg.

The analytical formulae are rectilinear; therefore, they do not allow for the curvature of the earth. Approximate calculation of the magnitude of the resultant error indicated that it is so small that it should not seriously affect the validity of the conclusions.

The gulfward increase of density need not be exactly as postulated in the assumptions. A lesser rate of increase of density would be equally possible if compensated by a sufficiently greater thickness of the substratum, or a greater rate of increase of density would be equally possible, if compensated by a sufficiently lesser thickness of the substratum. Differentiation between the basement and the substratum is not necessary, excepting for ease of calculation.

The results of the calculations and the relative fit of the calculated to the observed profile of Δg are shown graphically in Figures 3 A, B, C. Of the various sets of assumptions which were tried, the closest fit of calculated to observed profile of Δg was given by the assumption of the geosyncline plus the gulfward increase in density (Fig. 3A).

The results of the calculations seem to indicate: (1) that there must be a horizontal increase in density of the basement, from the general area of the Sabine uplift to the center of the Gulf of Mexico; and (2) that a geosyncline must be present in the surface of the basement, with the axes of its trough slightly landward from the position of the present coast line.

A speculative study of the theoretically probable position which should be taken by the geosyncline was made and the results are shown in Figure 4. The position of the coast at some date far back in the geologic past is assumed to have been at the position indicated. The smooth dashed curved line *B* is assumed to have been the profile of the basement of that date. The dotted line *C* is assumed to have been the profile of the continental shelf of that date. Geologic time since that date is assumed to have been divided into nine equal periods (for the purposes of simplification of the calculations); deposition of sediments is assumed to have been the same throughout all the periods; the insert in the lower left-hand corner of Figure 4 is assumed to give the profile of the prism of sediments which were deposited during each period. The profile of the present continental shelf is assumed to be the profile of equilibrium: subsidence is assumed to take place concomitantly with sedimentation so that at the end of each period,

the profile of the then continental shelf has the same general form as the present continental shelf. In the study, a prism of sediments of the profile in the lower left-hand corner of the figure was superimposed on *C;* the basement *B*, and *C*, were then depressed until the then continental shelf had the same profile as the present continental shelf. The superposition of the sediments and the depression were carried on until the continental shelf reached the position of the present continental shelf *D*. The line *A* gives the final position of the profile of the basement. A geosyncline necessarily was formed; and its trough lies immediately under the coast line. The results of such a study are

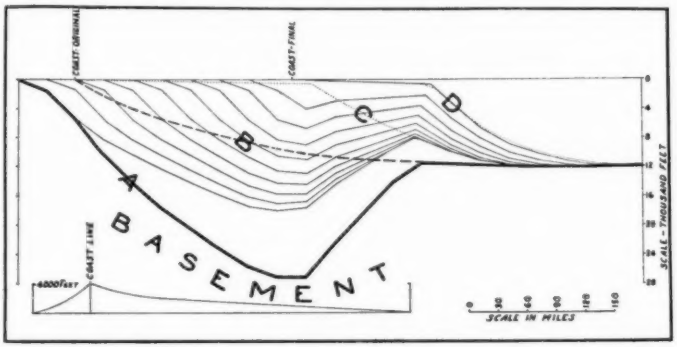


FIG. 4.—Study of formation of Gulf Coast geosyncline by subsidence concomitant with and equal to progressive sedimentation.

no better than its basic assumptions; and the latter need further consideration. But it is suggestive (1) that in drafting the geosyncline in Figure 1 A, B sections, it seemed necessary to put the trough line of the geosyncline at the coast line in order to get the basement up to a height within 2,000 feet of the base of the Sigsbee Deep without an implausibly steep rise; and (2) that the calculations from the regional variation of gravity place the trough line of the geosyncline only 25 miles inland from the coast (Fig. 3A).

The Gulf Coast geosyncline arouses isostatic meditation. The Texas-Louisiana Gulf Coast has been a (geologically) negative area at least since the beginning of the Tertiary. There have been short periods of positive movement which may have been produced, so far as is known, either by fluctuation of sea-level or by fluctuation of the level of the land, but, in the main, there has been continuing progressive subsidence. Evidence of compression since the beginning of the Tertiary is wanting; and the geosyncline doubtfully can be one of

those orogenic downwarps which are found fronting youthful mountain arcs. But isostatically, the Gulf Coast geosyncline must be, and for a long time must have been, negatively out of equilibrium. Subsidence continued, however, and presumably must have increased the lack of isostatic equilibrium, as the progressive depression of the basement has increased the negative gravity anomaly. The movement, therefore, has been the reverse of what would be expected from the theory of isostasy.

The subsidence seems perhaps to be the effect of the sedimentation. The two have seemed in general to have been equal throughout the time which is represented by the beds which are penetrated by the drill. The surface in the Gulf Coast seems to have remained nearly at sea-level; it seems at no time to have been far above or far below sea-level. The rate of sedimentation presumably in large part has been independent of the downwarping of the Gulf Coast geosyncline, as it must depend considerably on climatic conditions and the hinterland. The rate of sedimentation accidentally may have equalled the rate of subsidence. But the rate of sedimentation and the rate of subsidence seem to have maintained essential equality through a long period of geologic time; and contemporaneously, the rate of subsidence seems to have been greater in an area such as the Mississippi delta, in which the rate of sedimentation has been greater. The subsidence, therefore, seems more probably to be the effect of the sedimentation and to have tended to compensate it. But the subsidence can not be the effect of a movement toward isostatic equilibrium under the effect of the extra load of the sediments. Superficial yielding of the basement under the weight of the extra load of the sediments seemingly must have taken place without regard to the isostatic relations.

Dynamically, the yielding seems more easily explainable, not as an effect of the sedimentation but of some dynamic cause. Seidl,[4] for example, calls attention to the fact that in metal test blocks under tension, in the laboratory, the first yielding is inward bending of the outer layers of the test block and that similar incipient rupture of the earth's crust should produce a syncline or geosyncline. But the close equivalence of subsidence and sedimentation is not so easily explained by such a dynamic cause.

[4] Erich Seidl, "Bruch- und Fliess-Formen der Technischen Mechanik und ihre Anwendung auf Geologie und Bergbau," *Zerreiss-Form*, Vol. 3 (Berlin, 1930).

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RACCOON BEND OIL FIELD AUSTIN COUNTY, TEXAS[1]

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ABSTRACT

The Raccoon Bend oil field, located on the west side of Brazos River, Austin County, Texas, was discovered in 1928. There is little definite geophysical or surface geological evidence of this marked structural feature, although gas, sulphur water, and pyrite in shallow water wells are all common, and distinctive of the area. It consists primarily of a broad faulted dome having an uplift above normal in excess of 800 feet. The faults are of the normal type, and form several grabens over the central part of the dome. In addition to an Oakville gas sand at 1,000 feet, oil is obtained from two Jackson sands, one a very lenticular basal Whitsett sand, averaging 3,150 feet in depth, and the other a continuous sand near the center of the McElroy formation, averaging 3,475 feet in depth. The field has a proved area of 1,162 acres and has produced a total of 11,400,000 barrels of oil, or an average of 9,800 barrels per proved acre. The pressure of the field, which is operated solely by the Humble Oil and Refining Company, is being maintained by having gas returned to all three reservoirs. The present daily allowable is 4,500 barrels from 114 completed oil wells. About the same amount of salt water is also produced.

INTRODUCTION

The development of Raccoon Bend has aroused very intense geological interest because of the striking structural picture that has been unfolded. To a geologist approaching this feature from the faulted fields of the San Antonio area or central East Texas, the faults at Raccoon Bend might appear to be its dominant elements; to a geologist working among the domes of the coast, the domal characteristics of the field would appear to be the controlling factors. But no geologist can fail to be impressed by the neat structural arrangement of the area with its uplift of more than 800 feet; the collapsed condition of the dome, perhaps paradoxical; the influence the growing structure has had upon the normal sedimentation of the region; the evidence the field contributes toward the view that oil was formed close to its reservoirs, and that only a relatively short time elapsed between the formation of the reservoir and its filling with oil; and finally, that the faulting came after the accumulation of the oil and preceded the deposition of a large part of the section found at Raccoon Bend.

Acknowledgments.—The writers are grateful to Miss Alva C.

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[2] Geologists, Humble Oil and Refining Company.

Ellisor and the paleontological laboratory of the Humble Oil and Refining Company for the examination of a large number of samples and for determinations that have been of great assistance in developing the structural history of Raccoon Bend. The helpful comments of W. C. Spooner, L. T. Barrow, and H. D. Wilde, and discussions of the geology of the field and the character of the oil with these men and others, have been of inestimable value in molding the thought expressed in this paper. G. W. Jackson, of the petroleum engineering department of the Humble Oil and Refining Company, has made detailed studies of the gravity relations of the oil and has kindly permitted the use of his observations in this paper.

Location.—Raccoon Bend is on the west bank of Brazos River, in east-central Austin County, within a large bend of the river from which the name of the field is derived. The field is 8 miles east of Bellville, 7 miles west of Hempstead, and 60 miles northwest of Houston. It is about midway between the Hockley and Brenham salt domes, 20 miles from each, and 16 miles north of the Brookshire dome. It is 48 miles southwest of the Conroe field.

HISTORY

The site of the Raccoon Bend field has long been of interest. The Indians, as judged from their remains, had a permanent encampment on the McCasland land in the northeast part of the field; and General Sam Houston, on his way to the San Jacinto battle field, camped there also. Hayes and Kennedy[3] mention the "gray calcareous sandstone underlying grayish-blue calcareous . . . clays" at Cochran's crossing, on Brazos River, a few hundred yards above where now stands an oil well in the river.

The area had been of casual interest for a long time to the Houston oil fraternity because of gas encountered in shallow water wells, one of which on the Thompson place blew out (about the year 1919) in the course of its drilling; because of sulphur water in several wells; and because of lumps of pyrite in surface clays encountered in water wells. These favorable features were generally known, for several people had unsuccessfully attempted to interest Houston oil men in drilling the area; but there seems to have been prejudice against the region because of its distance back from the coast.

To Harry Pennington credit is due for realizing the significance of the area and for finally assembling the block of leases in 1926 which ultimately resulted in the discovery of the field. Conroe Booth, of

[3] C. W. Hayes and William Kennedy, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *U. S. Geol. Survey Bull. 212* (1903), p. 32.

Chapel Hill, a water well driller, was preparing to drill a shallow well to find gas in the Raccoon Bend area when Pennington became acquainted with him and the prospect. Pennington's block was sold shortly after to Henry Staiti, of Houston, who drilled Thompson No. 1, in September, 1926, a shallow well intended to test the gas possibilities. This well developed enough gas to require that the titles on the block be immediately cleared and further drilling operations were temporarily suspended, although later, at 1,009 feet, 35 barrels of 17° Bé. oil were produced daily from the well for a few days. Just prior to the discovery of gas in this well the block was offered to the Humble Company by Staiti, and through the favorable recommendation of Frith C. Owens, of the Humble Company's Gulf Coast geological department, an agreement was made whereby the Humble was to spend a certain amount of money on the block for exploratory and development work. Early in 1927, after 14 shallow tests ranging from 1,000 feet to 1,700 feet in depth, had been completed, of which 10 were gas wells and one a small oil well, a dome that covered approximately 4,000 acres and had 130 feet of closure, was outlined on a gas sand about 1,000 feet in depth.

A deep test, Bellville School No. 1, in the Wm. Smeathers Survey, was then commenced at a point that later turned out to be less than ½ mile north of the nearest production. Although this well went to 4,066 feet, or 800 feet below the top of the McElroy formation of the Jackson series, and had showings of oil and gas in Whitsett and McElroy sands, it did not produce. Next, a deep test, Reese No. 2 in the north part of the Wm. C. White Survey, was drilled, which proved to be in a dry spot a few hundred feet east of later production. This well was 3,363 feet deep and terminated just below the basal Whitsett sand. The sands in the Jackson series in these wells were poor, although they contained a little oil. The third deep test, Gutoskey No. 2, on the south edge of the present field, in the south-central part of the Wm. C. White Survey, and more than 2 miles south of the first deep test, on February 3, 1928, found a well saturated body of sand at 3,282 feet that initially made about 300 barrels daily on a half-inch choke. This is considered the discovery well of the field and its producing sand, in the basal 40 feet of the Whitsett formation, is known as the Gutoskey sand. In May, 1929, 255 feet below the top of the Gutoskey sand, and 205 feet within the McElroy formation, a second producing sand, which has been called the Grawunder sand, was found in Humble, Grawunder No. C-1, at 3,430 feet, although most later wells in this horizon found it 320 feet below the top of the upper sand.

TOPOGRAPHY AND DRAINAGE

The area of the Raccoon Bend field has a gently rolling relief with a topographic "high" nosing southeastward, suggesting the appearance of a surface dome, although in reality merely a coincidence caused by erosion because of proximity to Brazos River. The high point of this feature is in the northwest part of the W. C. White Survey, including the Bracey, Sherrill, Beal, and adjoining properties. The maximum elevation is approximately 178 feet, and there is probably a drop of at least 10 feet toward the west and northwest and a much sharper and greater drop northeast, east, and south. The elevation along the river is 124 feet and on the terraces above it is 140 feet.

In addition to the drainage afforded by Brazos River, the field is drained by Caney Creek, which flows into the river on the north, and by Ives Creek and Piney Creek on the south. Aerial maps emphasize the earlier meanders of Brazos River, which remain as ox-bow lakes. Stone Lake, lying a few thousand feet northeast of the producing area, is an earlier channel of the river, and a still earlier channel ½ mile west of Stone Lake, and visible from the air, suggests the influence the dome has had in diverting the course of Brazos River eastward. Other less apparent ox-bows remain farther south on the west side of the river, but on the east side none occurs east of the field. The earliest survey made of the river in 1824, when compared with its present course, shows the tendency of the river to work eastward. About a mile south of the field there was a large lake now drained, covering about 1,500 acres, which was apparently caused by water standing in a low area following a particularly high stage of the river.

GENERAL SURFACE FEATURES

Gas.—The area has long been known for the occurrence of gas in shallow water wells. Accredited evidence indicates that this gas was recognized as far back as 1874. At the present time two shallow water wells are bubbling gas. One of these is located on the Machemehl land, very close to the south corner of the William Smeathers Survey, and within the productive area of the field. The other well is ¼ mile south and on the Thompson land in the Wm. C. White Survey. The Machemehl well is 93 feet deep. Gas began to show in this well as high as 50 feet. The Thompson well is 70 feet deep and gas is bubbling constantly through the water which stands 20 feet high in the well.

Sulphur water.—Several sulphur water wells are known within the productive limits of the field. The area showing sulphur water is

larger than that showing shallow gas. It extends from the J. W. Wilson tract in the Wm. Harvey League northward to Stone Lake. The best sulphur water wells occur on the R. W. Payne tract (40 feet in depth); on the Rivers Jennings tract (now Machemehl) on the shore of Stone Lake; and on the J. W. Wilson property. While drilling the Wilson well, sulphur water was noted at 40, 55, and 67 feet. Several other distinct sulphur water wells are in this area.

Pyrite and sulphur.—The occurrence of pyrite, either imbedded in the surface clays as nodules some of which are 3 or 4 inches in diameter, or as grains and fragments in sandstone, is an interesting feature of the field. Native sulphur has also been found in samples of sandstone from shallow wells drilled for water.

Induration of shallow sands.—Prior to the discovery of oil, water-well drillers report that at depths ranging from 22 feet to 90 feet hard sandstone was encountered within the Raccoon Bend area. This feature is exceptional, since such shallow sands are not indurated in the surrounding area. This sandstone seems to be localized principally between the north corner of the Wm. Harvey League and the south corner of the Wm. Smeathers League, corresponding closely with the areas of gas and sulphur water. This suggests that mineralized waters, indirectly resulting from the oil beneath, have produced this induration.

The localization of these significant surface features ranging from 500 to 1,500 feet north of the largest fault (normal and downthrown toward the south) expressed by subsurface data suggests some connection with the reservoir of oil and gas below.

GEOPHYSICS

It is natural that one should inquire what results geophysical methods have shown at Raccoon Bend. However, other than gravity work, which indicates that a very deeply buried salt mass probably lies below, there is little definite information. Refraction seismograph work showed nothing definite, and the results of reflection work were very unsatisfactory. This was due to many causes, the most important being the large number of high tension lines in the vicinity of the field.

STRATIGRAPHY

At Raccoon Bend, Lagarto clay and a later sand, probably of Lissie age, are at the surface (Fig. 1). No Goliad is known in the immediate area and the presumption is that it has been overlapped down the dip by the Lissie. The first 1,000 feet, down to the shallow gas sand, is assigned somewhat arbitrarily to the Lagarto (Pliocene), and the next 400 feet to the Oakville (Miocene). The ordinary character-

istics of the Lagarto-Oakville section in this part of Texas prevail: plentiful, reworked Cretaceous foraminifers in the clays, some of which are so perfectly preserved that they could easily be mistaken for indigenous remains; fragments of bones and teeth of Pliocene and Miocene forms, and larger reworked Cretaceous fossils in the sands;

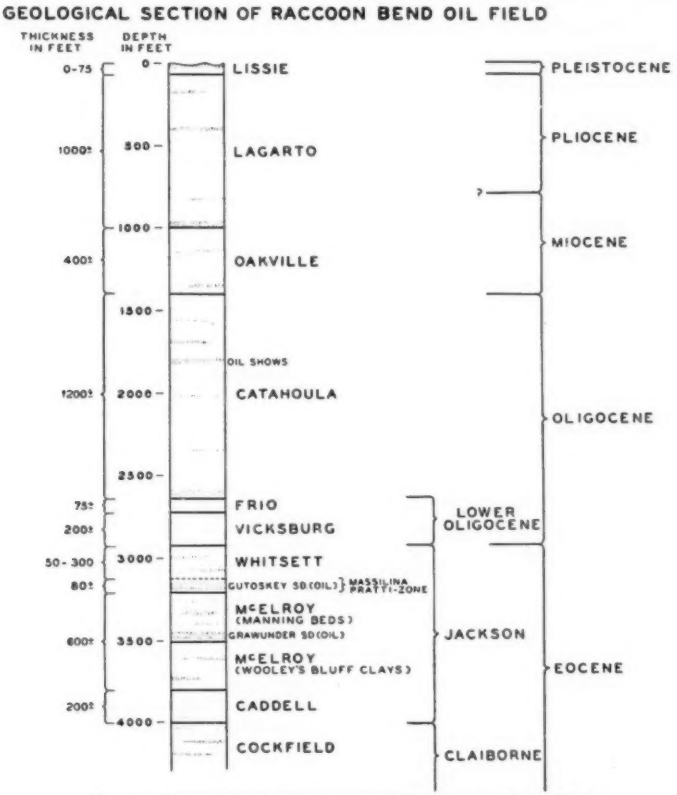

FIG. 1.—Geologic column encountered in Raccoon Bend field.

gray, green, yellow, or red calcareous clays, with calcareous nodules; and subordinate beds of impure ash.

Closer to the coast, the Pleistocene, Pliocene, and Miocene beds afford few definite lithological or paleontological markers. The markers that do occur have been rarely cored sufficiently, or in a wide enough area, to give accurate data, so that the Middle Oligocene lying below the Miocene coastward is, with its three divisions, the best

structural guide, at least, for the first two tiers of coastal counties. However, at Raccoon Bend no Middle Oligocene is recognized, as it appears, from present data, to be overlapped by the ash-bearing Catahoula beds which continue onto the Frio below, farther down the dip.

At Raccoon Bend the series of ashy clays, with beds of "rice" sand near the base and at present included within the Catahoula, lies next below the Oakville. This series is about 1,400 feet thick. The thinning seaward, or the lost identity of the ashy Catahoula phase, of Oligocene or Miocene age, and the marked thickening seaward of the less ashy Frio, which is only 200 feet thick at Raccoon Bend, are notable features of the general geologic section.

The Frio, with its sands, lignite, and non-calcareous semi-marine clays, is assigned to the Lower Oligocene because wells in the Frio show fossil beds nearer the gulf containing a fauna that is distinctly Lower Oligocene in type. Beneath the Frio the dark gray and blue clays of the Vicksburg, 100–200 feet thick, occur with the same fauna that is recognized on the surface in Mississippi, and appearing in the same sequence. A few miles up the dip from Raccoon Bend, the Vicksburg appears to be completely overlapped by the overlying Frio, or at least it has not been recognized at the surface. The Vicksburg beds at Raccoon Bend seem to belong to the lower phase of this formation, because, nearer the gulf, zones younger in age are found successively above the phase found at Raccoon Bend, until at Goose Creek, 75 miles down the dip from Raccoon Bend, more than 1,000 feet of beds assignable to the Vicksburg occur, distributed through two or more distinct faunal zones. A considerable part of the upper Vicksburg is therefore missing at Raccoon Bend. Because of the difficulty of separating the Frio and Vicksburg at Raccoon Bend, the writers have arbitrarily used the combined Frio-Vicksburg section as a unit in this paper. In other words, the first shell fragments are regarded as the top of the Frio-Vicksburg section and the first Whitsett fossils as its base. Undoubtedly the top of the Frio can be placed higher, certainly as high as the first lignite, but the shell fragments appear to the writers a more definite local marker. The difficulty in delimiting these two formations arises from the fact that as one goes gulfward the upper non-marine beds, paleontologically unassignable to any formation, become successively marine and contain a Vicksburg fauna.

Directly beneath the thin Vicksburg at Raccoon Bend lies the dark gray-to-blue marine clays of the Whitsett, the upper formation of the Jackson series, at whose base is the upper producing sand at Raccoon Bend. The Whitsett ranges from 183 to 261 feet in thickness

in the field, compared with a thickness ranging from 250 to 300 feet away from the structure.

The McElroy, the middle formation of the Jackson, composed of brittle dark blue-to-brown clays, ranges from 600 to 700 feet in thickness in the Raccoon Bend area. There is little real evidence on top of the dome to show that the McElroy has sustained thinning over the dome. About 280 feet in most places, below the top of the McElroy, is the lower producing sand which seems to be the equivalent of the Wellborne sandstone on the surface, although thin irregular sands occur locally between this sand and the top of the McElroy. The upper part of the McElroy (Manning beds) overlaps the lower part (Wooley's Bluff clays) onto Caddell up the dip from Raccoon Bend, so that although the entire McElroy section occurs here, the upper 300 feet only continues to the surface.

In the productive area only two wells have reached the Caddell, the lowest member of the Jackson, which has its usual uniform thickness of approximately 200 feet with the characteristic marly greensand at the base and the dark blue-to-brown clays above. The Caddell seemingly has been little reduced in thickness by the uplift, although the wells that have passed through it are not on top of the dome, so that definite conclusions are impossible.

A few outpost wildcats around the field have penetrated the Claiborne series through the Cockfield, and as much as 400 feet into the Upper Saline Bayou formation, and have found these beds practically normal. It is difficult to divide the marine Cockfield from the marine Upper Saline Bayou at the dip position of Raccoon Bend, because non-marine beds between these fossil zones are being replaced by fossiliferous beds, even within short distances, and the dividing line between the marine phase of the two formations shifts within short distances. Sands have been found in these wells in the Claiborne, but they contain no oil. The closest well to have penetrated the complete Cockfield is one mile north of the producing area (Humble, Reese No. B-1) in the southeast part of the Wm. Smeathers Survey. A well (Humble, E. B. Wilson No. 1) 3,500 feet northwest of the producing area, in the M. R. Williams Survey, penetrated the Conroe horizon at a depth of 4,500 feet, but found no oil, although a sandy section occurred.

Later on in this paper, the effect the uplift and the faulting has had upon the normal section, and upon the development of sand thicknesses in excess of the normal amount of sand, will be discussed (Table IV). A generalized section is given in Figure 1, and a resumé of the variation in thickness and in sand content is shown in Table IV.

STRUCTURAL GEOLOGY

SURFACE

The surface stratigraphic evidence of structure at Raccoon Bend, so far as developed, is not in keeping with the notable uplift beneath. It is true that clay, probably of Lagarto age, extends down Brazos River a little farther than is considered normal, and it is also true that the field itself lies in a widened area of clay that is more or less enveloped by younger Lissie sand on the west and north, but areas of similar clay so surrounded by apparently younger sand are not exceptional in the Lissie outcrop throughout southeast Texas. Many of these seeming clay inliers have been proved quite normal by subsequent drilling, and they appear to be windows of the irregular Lagarto clay surface lying disconformably below the Lissie and exposed by normal erosion. Four miles south of the field, low hills showing Lagarto clay 40 feet above the level of the Raccoon Bend field reflect no subsurface structure.

At the time the Humble Company was considering the acquisition of Raccoon Bend, practically no detailed mapping of the region involving the so-called Lagarto inliers had been done, nor was there time before a decision was necessary, to detail a large area to determine the exact regional relations of the Lagarto at Raccoon Bend; consequently the significance of this clay may have been given more weight than the actual conditions justified. Probably sandstone lenses and beds in the Lagarto could, if sufficiently detailed, be shown to slightly reflect the structure. Surface work of such a detailed type, however, is not available now.

East of Brazos River, and $2\frac{1}{2}$ miles east of the field, in Waller County, clays somewhat similar in type to those of the Lagarto are found which are definitely assignable to the upstream phase of the Beaumont of Pleistocene age. The gas and sulphur water that has been known locally for years in the shallow water wells at Raccoon Bend, and the masses of pyrite encountered in shallow wells, were the most definite surface anomalies of the area.

SUBSURFACE

The structural feature revealed by the shallow tests to the top of the 1000-foot gas sand (Fig. 2) covers about 4,000 acres, extending 6 miles east and west and $3\frac{1}{2}$ miles north and south. Its center lies a mile west of the structural center on the Jackson (Fig. 3). There is 130 feet of total closure here, about 70 feet of which is gas productive. An uplift ranging from 200 to 250 feet exists on this sand. The sand is correlated with that cropping out a few miles north of Brenham, in

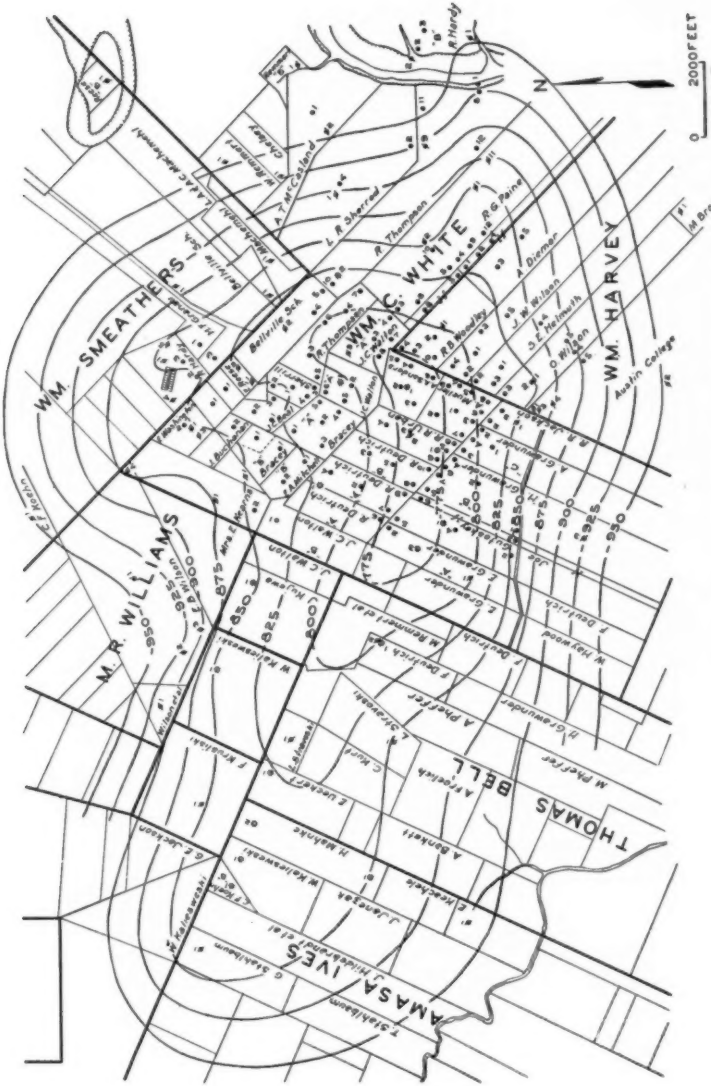

FIG. 2.—Geologic structure map contoured on top of 1,000-foot (Oakville) gas sand, Raccoon Bend field.

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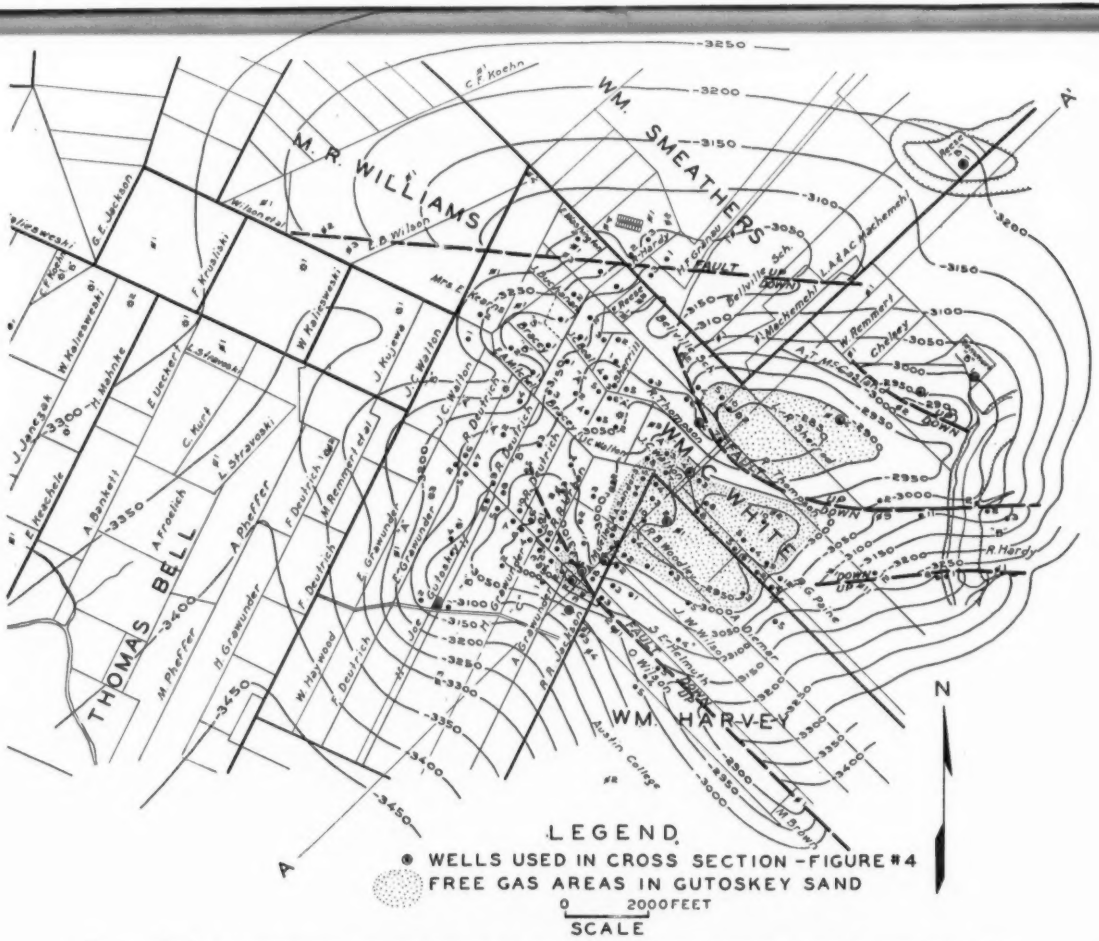

FIG. 3.—Geologic structure map contoured on top of Gutosky (basal Whitsett formation) sand, Raccoon Bend field.

Washington County, or about 24 miles up the dip from Raccoon Bend, a sand considered to be at the top of the Oakville formation. Its normal dip is thought to approximate 50 feet per mile. The Oakville gas sand is about 40 feet thick, but only 8 or 9 feet contain gas. Although the original gas-producing area was about 2,500 acres, it has been greatly reduced by withdrawals for commercial uses. The porosity of the sand is about 25 per cent. Although this gas may have come up from below through very small faults, as the gas of the shallow water wells may have done, the writers can not prove, with the evidence at their disposal, that such faults have affected either the shallow gas sand or the surface beds.

The structure in the 1,000-foot Oakville gas sand does not conform with the structure on the Jackson beds, either in amount of closure or geographic position. The shallow gas area extends 1.5 miles west of the westernmost oil well and the center of the 1,000-foot structure is approximately a mile west of the center of the Jackson structure. This structural offset within a vertical distance of 2,000 feet may be readily explained by assuming that the deforming force came from the east or southeast so that the structural axis was inclined eastward, resulting in a progressive eastward movement of the structural apex with depth.

With depth the uplift also becomes rapidly emphasized, for the McElroy is more than 800 feet above its normal position at Raccoon Bend (Fig. 3). Normally the 3,650-foot sub-sea contour on the top of the McElroy should pass through the site of the field. The highest actual value on the top of the McElroy in the field is 2,890 feet sub-sea on the north side of the graben, and 2,920 feet sub-sea on the south side of the graben. However, from Humble, McCasland No. 2 (Fig. 5), which cut a fault within the McElroy section and reached the Caddell at 3,598 feet, the writers infer that the reconstructed top of the McElroy on the high side of this fault would occur at least as high as 2,730 feet sub-sea. This well is therefore the highest well structurally in the field. Humble, Minnie Brown No. 1 (Fig. 5) presents a similar condition, as it passed from the low to the high side of another fault and found the top of the Caddell at 3,618 feet. By reconstructing the McElroy lost in this well by faulting, its top is placed at 2,869 feet sub-sea. The two highest wells structurally in the field thus lie along faults and are approximately 3,500 feet east of the present center of the structure. If the section in the Minnie Brown well is reconstructed, using the low side of the fault (Vicksburg as low as 3,305), the McElroy should occur on this side at least as low as 3,424 feet sub-sea, which is 200 feet lower than the contours show. Such a

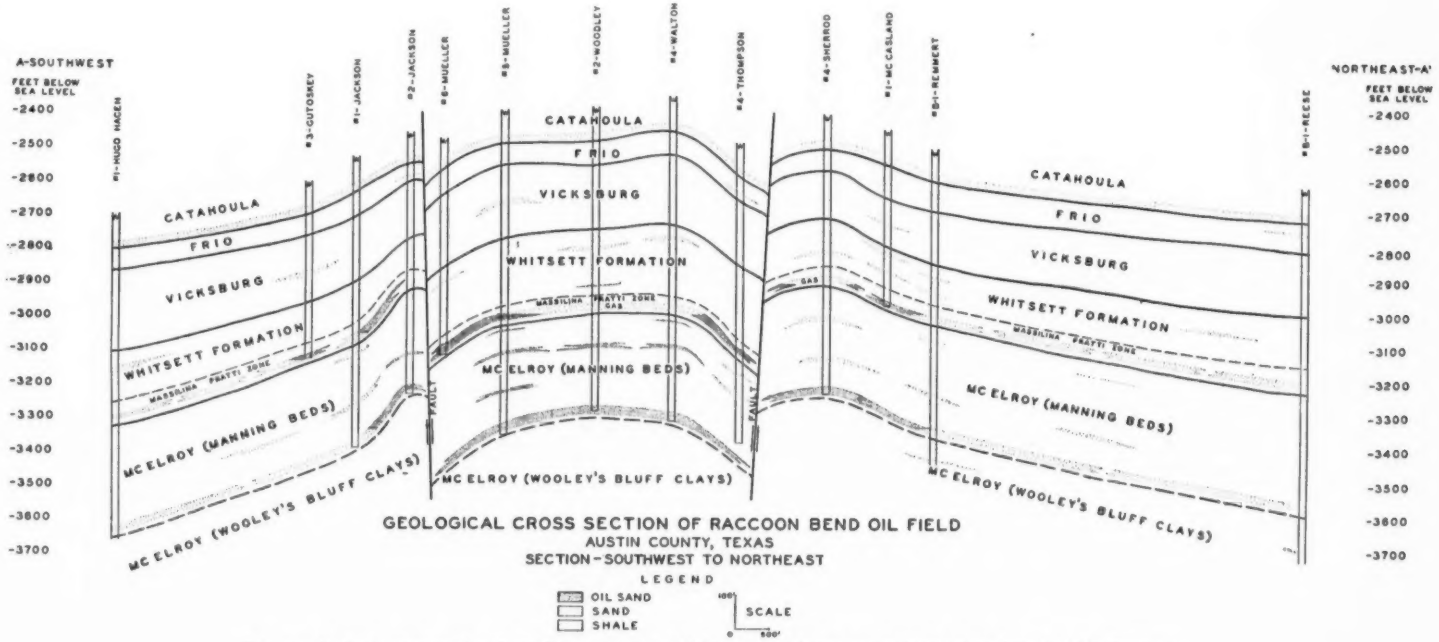

FIG. 4.—Geologic cross section through Raccoon Bend field from southwest to northeast along line A–A' in Figure 3.

steep drop southeastward is improbable, especially as the first Frio shells were encountered in a position corresponding with that contoured, so that the presumption is that faulting has created abnormally low and high areas adjacent to the faults, probably with very steep dips for short distances toward the fault planes. This well is evidently cutting highly dipping beds so that the appearance of greater thickness results.

The Raccoon Bend uplift is in a regional synclinal area which does not have the structure of a rim syncline[4] peculiar to some shallow salt domes. This implies that salt from the region around the structure might have flowed into the area under Raccoon Bend to help build it up so that the surrounding area was depleted of salt and caused a sagging of the overlying formations in an irregular fashion around the structure.[5] The probable great depth to the salt, and the magnitude of the region over which the structure is expressed, suggests that the surrounding area, depleted of salt, would also be relatively large.

The abnormally high structural area on the McElroy formation extends 9 miles north and south and 6½ miles east and west, and covers approximately 32,000 acres, although the productive Jackson area apparently will not exceed 1,800 acres. If the low area around the uplift is attributed to the structure, the total structural abnormal area of the Raccoon Bend uplift, as depicted by the McElroy, includes 50,000 acres, or 78 square miles.

A broken ring of fairly deep tests drilled to prove or disprove the extent of the structure shows a southward nose which causes the Raccoon Bend structure to depart from a roughly circular outline by almost 2 miles. For example, the 3,500-foot sub-sea contour on the top of the McElroy is deflected southward about 2 miles.

The actual amount of closure on the McElroy is 450 feet, with 90 feet of this productive in the Grawunder sand, and 350 feet productive in the Whitsett sand. The total Whitsett closure is slightly less than that on the McElroy. These closures contrast with only 130 feet of total closure, and 70 feet of gas-producing closure, on the 1,000-foot Oakville sand.

Faulting.—Although the general aspect of the Raccoon Bend feature is distinctly domal, the dome, however, has collapsed at least

[4] E. A. Wendlandt and G. Moses Knebel, "Lower Claiborne of East Texas with Special Reference to Mount Sylvan Dome and Salt Movement," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1347–75, especially pp. 1369 *et seq.*

[5] See also Donald C. Barton, "Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Salt Domes of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 9 (September, 1933), pp. 1025–83.

relatively, near its top, in several stages. The boundaries of the collapsed areas are faults (Fig. 3). The four principal faults have average throws of approximately 235, 240, 114, and 230 feet, respectively, from the northernmost fault to the southernmost fault. The evidence of faulting consists of (1) sharp drops between adjoining wells, in some places less than 500 feet apart, on faunal markers, lithologic markers, or oil zones; (2) absence of part of the section, or of entire units, indicated by greatly reduced faunal or lithologic intervals; (3) actual fault planes cut in coring, so that sand may lie against shale (Thompson No. 8, at 3,266 feet); (4) highly dipping strata (15°–70°)

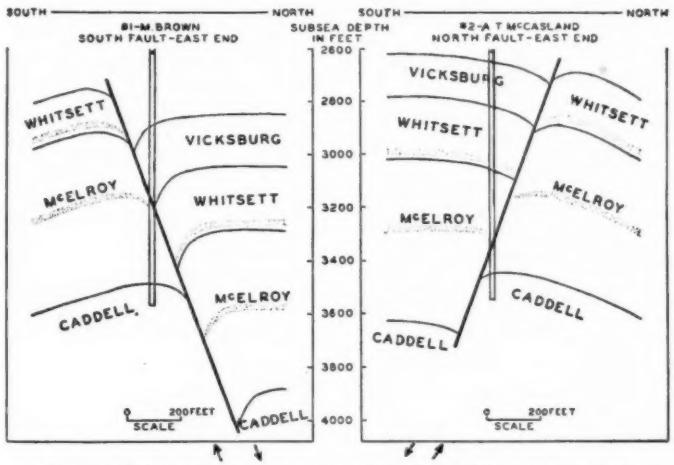

FIG. 5.—Detailed geologic cross sections through two Raccoon Bend faults. Arrows indicate fault movement.

noted in cores at or near the position of the fault plane determined by other means; (5) indurated sand or sandy shale sections near the suspected fault plane, stained with oil, but not capable of producing. The general cross section (Fig. 4) and the detailed sections (Fig. 5) best show these conditions. Faulting explains why the highest areas structurally are not at the center of the structural area but on the high or outer sides of the central graben. In fact the closed area at the center of the main graben ranges from 23 to 52 feet lower than the high areas on either side of this graben. The inner graben ranges from 0.25 to 0.5 mile wide, and at least 1.5 miles long; and the outer graben 1.5 to 2 miles across, and approximately 2.5 miles from end to end. The average strike of the four principal faults is N. 65° W., which is comparable with a very general regional strike of N. 45° E.

A short fifth fault undoubtedly passes between Humble, McCasland Nos. 1 and 2, and it may continue northwestward several thousand feet farther. In any event Humble, McCasland No. 2 furnishes excellent fault evidence in that the McElroy was reached at 3,212 feet and the Caddell at 3,598 feet, giving a McElroy thickness of only 386 feet, or a loss from normal of 224 feet. This infers a throw of 224 feet as compared with an average throw of 235 feet for the north fault obtained by correlating wells along this fault on the west.

It is suspected from the records of Mueller No. 3, Thompson No. 7, Ollie Wilson No. 5, and others, that the beds on the high sides of faults dip toward the fault planes a short distance back from the fault (Fig. 3) and from the general structural picture that the beds on the low sides dip similarly. This condition occurs along the Luling fault[6] and probably exists at Salt Flat and Darst Creek. The low Vicksburg in the Minnie Brown No. 1 suggests a sharp dip toward the fault plane on the low side.

Although many wells cut the fault planes, the fault dips are not accurately known. It is believed that the typical dip is 70°–75°. The best clue to a fault dip is between Humble, Mueller No. 3, a low-side well, and Mueller No. 6, a high-side well, along the south fault. These wells show a throw of 186 feet on the Gutoskey sand. The fault, along its ordinary strike here, must pass within less than 25 feet of both wells, so that it must dip at an angle of about 75°. Humble, Thompson No. 8 actually cuts a fault at the base of the Whitsett oil zone, as revealed in a core from 3,266 feet. Humble, Minnie Brown No. 1, at the southeast end of the south fault, has had all of the Whitsett removed and evidently 350 feet of the Manning beds (upper McElroy), since this well passed from the low to the high side of the fault, or from Vicksburg (3,305 feet) directly into McElroy (3,325 feet). This would normally indicate a displacement of 550–600 feet, but due to thinning of the normal Whitsett and McElroy section over the top of the dome or for other reasons, the actual displacement here may not exceed 350–400 feet (Fig. 5). Apparently this well cut over to the high side of the fault just far enough back from the plane to reach the crest of the fold before it dips in toward the fault. The structural uplift may also be more pronounced in the Caddell, which could further explain the greater displacement.

Humble, Thompson No. 4 showed a 25° dip at 3,450 feet in the Whitsett and Thompson No. 9 showed slickensided cores at 3,632 feet in the McElroy. Paine No. 11 had a 17° dip in a core at 3,272

[6] E. W. Brucks, "The Luling Field, Caldwell and Guadalupe Counties, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), p. 641.

feet at the Whitsett-McElroy contact, and a 20° dip at 3,526 feet. Humble, Reese No. 3 showed dips ranging from 40° to 85° at 3,456 feet.

Proximity to faults in the field may greatly decrease the amount of oil sand either by faulting it out or by squeezing so that the normal sand section is interrupted or pinched and its oil saturation limited, as well as hindered by cementation due to precipitation close to the fault plane. On the east side of the field faults have been particularly damaging to the Gutoskey sand (Humble, Thompson No. 9; Paine No. 11, and Duncan State-Land No. 2) resulting in barren areas, reducing the productive acreage somewhat, and adding to the reputation of the field for spottedness. In the Grawunder sand the faults have had relatively little effect in reducing the porosity of this reservoir, but by acting as barriers to water they have added to its productivity.

It is of considerable interest to record that in the repressuring operations at Raccoon Bend it has been found that movement of the gas is evidently not hindered by fault planes, but it is known to pass from one well to another directly across and up through fault planes. For example, by the use of odorizers introduced into key wells on the Mueller lease, north of the south fault, it was learned that this gas crossed the fault and was detected in the Grawunder C wells on the south, or high side. This confirms the view that gas travels much more easily than oil or water through strata, or along fault planes, because these same faults which have had no difficulty in excluding oil or water oppose no barriers whatever to the gas.

PRODUCING SAND CONDITIONS

The Whitsett, or Gutoskey zone, has an average thickness of 17 feet of clean sand, although in one well, J. W. Wilson No. 1, 40 feet of sand was found. The sand section in the Whitsett is thicker and cleaner than that in the surrounding wildcats (Table IV). This producing horizon is exceedingly lenticular and the gravities of its oils range from 14° to 30° Bé. The McElroy, or Grawunder zone is more porous and much more uniform than the Whitsett sand, although some lensing may occur. This sand is 15–25 feet thick, with an average of 18 feet of clean sand. The average gravity of the oil in wells in this sand within the graben area varies from 31° to 33° Bé.

The present proved productive area of the field in both sands is about 1,162 acres, of which 350 acres are productive in the Grawunder sand, which is coextensive with all of the Gutoskey gas area and with 125 acres of the Gutoskey oil area. An additional 360 acres have possibilities in the Jackson sands, but are as yet unproved.

Water levels.—In the Gutoskey, or upper sand, with its many lenses, the depth of the water level ranges from below 3,274 feet sub-sea on the west side to 3,105 feet sub-sea on the east side, and to 3,015 feet sub-sea on the south side. Evidently different sand lenses, separated from other lenses, have distinctive water levels. Some lenses far down on the structure still show very little water (Kearns No. 1), though other lenses much nearer the apex showed water early in the life of the field.

In the deeper, or Grawunder sand, the water level varies, depending on which side of the fault it is. In fact no Grawunder well in the graben has shown appreciable water, probably because this area originally occupied the apex of the dome and was initially free of water. It subsided, at least relatively, and has been protected from advancing water by the faults. This is readily understood because in wells (Humble, Thompson No. 9 and No. 11, McCasland No. 2, and State Land No. 2) which reached the producing horizons close to fault planes, the sand was found either pinched out, contaminated with shales, or cemented, apparently by water action along the fault plane. The amount of throw of the faults is also such that the sand sections are faulted against shale sections, providing a further seal. On the high, or outer sides of the faults, the water level is higher, being uniformly about 3,260–3,270 feet sub-sea on all sides of the field. The water is also plentiful outside the graben, as there are no barriers to prevent its advance, and percentages of 80–90 in Grawunder sand wells are now common.

Gas-oil levels.—It is of interest to note that the gas-oil level in the Gutoskey sand in the graben is approximately 2,990 feet sub-sea compared with a gas-oil level above 2,962 sub-sea on the south side of the graben (Grawunder C lease); and about 2,900 feet sub-sea on the north side of the graben (McCasland and Sherrod leases). This variation in the gas-oil level in the Gutoskey sand indicates a difference due to individual sand lenses. Had this reservoir been continuous prior to faulting, the assumption is that all the gas would have sought a common level (2,990 feet sub-sea). Following faulting of individual free-gas-bearing lenses, the more fugitive gas may have escaped from the Grawunder C, Sherrod, and McCasland leases into such upper sands as were also affected by the faulting.

The central gas cap in the Gutoskey sand occupies a continuous body of rather clean sand having an area of 225 acres. This is natural because it is probable that the highest part of the structure, where the currents were swiftest, would contain the coarsest and cleanest sand, and the muddier, more lenticular sands would occur farther down the

slopes of the structure. Although most of the free gas occurs at the structural apex in the Gutoskey sand, the several lenses also contain variable amounts of gas.

As no free gas exists in the Grawunder sand, no gas-oil level can be definitely ascertained.

RELATION OF OIL TO STRUCTURE

Gutoskey sand.—In the Whitsett, or Gutoskey sand, accumulation of the oil corresponds only approximately with the structure. This is because of a number of separated sand lenses that seem to have no connection with one another. Therefore, instead of the oil (and gas) being perched at the apex of the structure, it is distributed in many separate bodies concentrated near the apex but which extend farther down the west side than the southeast and east sides of the structure. The oil occurs, in horizontal distance, about 3,000 feet farther out from the same structural contour on the west side than on the other sides, and structurally it occurs 175 and 230 feet lower, respectively, on the west side than on the east and southeast sides.

The isolation of the oil into separate areas or lenses in the Gutoskey sand is proved by the following facts: (1) the association of oil of similar gravity in certain areas, such gravities having ranged from 14° to 34° A.P.I.; (2) the variation in the pressures required to inject gas in various groups of wells, the oil of each group of wells so responding being similar in gravity and character; (3) the unequal decline of bottom-hole pressures throughout the field, individual lenses reflecting individual declines; (4) the variation in the gas-oil level and in the oil-water level in certain groups of wells; (5) the difficulty of correlating sand bodies in the Gutoskey zone from area to area.

The lenticularity of the Gutoskey or Whitsett sand is notable. The variation in the gravity of this oil may be explained by its occurrence in numerous discontinuous lenses. There are at least 11 such lenses (Fig. 6). Stratigraphically they occupy the same general position at the base of the Whitsett. However, there is a variation in the distance from the top of the Gutoskey sand to the top of the McElroy formation of as much as 20 feet, although the average interval is about 40 feet. The fact that almost every lense has an oil of different gravity, the lighter oil in general occupying the upper part of the structure, and the oil rather irregularly becoming heavier farther down the sides of the structure, suggests that the oil (and gas) may have formed from source matter close to the individual sand lenses. Not only is the oil in these individual lenses of different gravity, but analyses of oil from 20 Gutoskey wells at Raccoon Bend shows more

fundamental differences[7] (Table I). For example, the 23° Bé. oil shows a higher cold test which indicates an increase in paraffine, and there is also a larger amount of lube stock in this oil than in the 19°–20° oils.

TABLE I

ANALYSIS OF OILS IN WHITSETT (GUTOSKEY) SAND AT RACCOON BEND

Well	*Gravity Baumé*	*Viscosity*	*Sulphur*	*Gasoline 400° E.P.*	*Kerosene*	*Gas-Oil An. Pt.*	*Lube per Cent*	*Cold Test*	*Bottoms*
Deutrich 9	19.6	147/100	0.18	—	—	40	40	0	18
Deutrich 6	20.6	165/100	0.15	—	—	46	40	0	14
Gutoskey 5	20.4	175/100	0.12	—	—	41	39	0	20
McCasland 1	20.3	320/100	0.17	—	—	40	40	0	20
Grawunder B-5	20.8	146/100	0.22	—	—	45	36	0	17
Deutrich A-7	21.0	157/100	0.17	—	—	40	43	0	17
Deutrich 8	21.4	148/100	0.20	—	—	50	35	10	13
Gutoskey 6	21.4	136/100	0.25	—	—	45	40	0	14
Grawunder B-6	22.1	67/100	0.15	—	—	45	35	20	20
Grawunder B-7	22.1	125/100	0.17	—	—	53	37	0	10
O. Wilson 4	22.1	135/100	0.21	—	—	38	38	25	23
Sherrod 4	22.7	77/100	0.108	5.4	18.7	20 120	35	50	15
Mueller 7	23.6	84/100	0.15	—	—	52	35	0	12
Deutrich B-10	22.5	114/100	0.12	—	—	50	30	0	20
Grawunder B-4	22.8	110/100	0.12	—	—	53	30	30	17
O. Wilson 2	23.0	105/100	0.15	—	—	45	40	35	13
Grawunder C-4	23.2	53/100	0.16	—	—	50	30	30	20
Hardy B-2	28.9	50/100	0.23	17.6	—	47	25	35	—

The general arrangement of the oil in accordance with its gravity and other characters about the structure suggests a uniform change in source matter from the apex of the structure downward. Variation in current velocities with depth over the growing submarine dome in early Whitsett time might explain such a dispersal of source matter about the apex of the feature. It is quite possible that certain forms of life were concentrated in certain areas around the incipient submarine dome because of more favorable environment, or bottom conditions, so that variation in the oil (or gas) that was formed, resulted. In the seas to-day life favors the shoaled areas[8] because of plentiful food or more favorable bottom conditions. Possibly in Jackson time a structural shoal that was to become the Raccoon Bend field presented a variety of depths from its apex downward, and equally variable conditions, more or less concentrically arranged, for the sustenance of various types of life, whether they were microscopic forms or larger types.

But the distribution of the various oil types is far from a complete function of the structure. The lighter oils are not confined entirely to the higher lenses. Reference to Figure 6 shows how these lenses with

[7] Suggested verbally by H. D. Wilde, Jr.

[8] Parker D. Trask, *Origin and Environment of Source Sediments* (1933), Gulf Publishing Company, Houston, Texas.

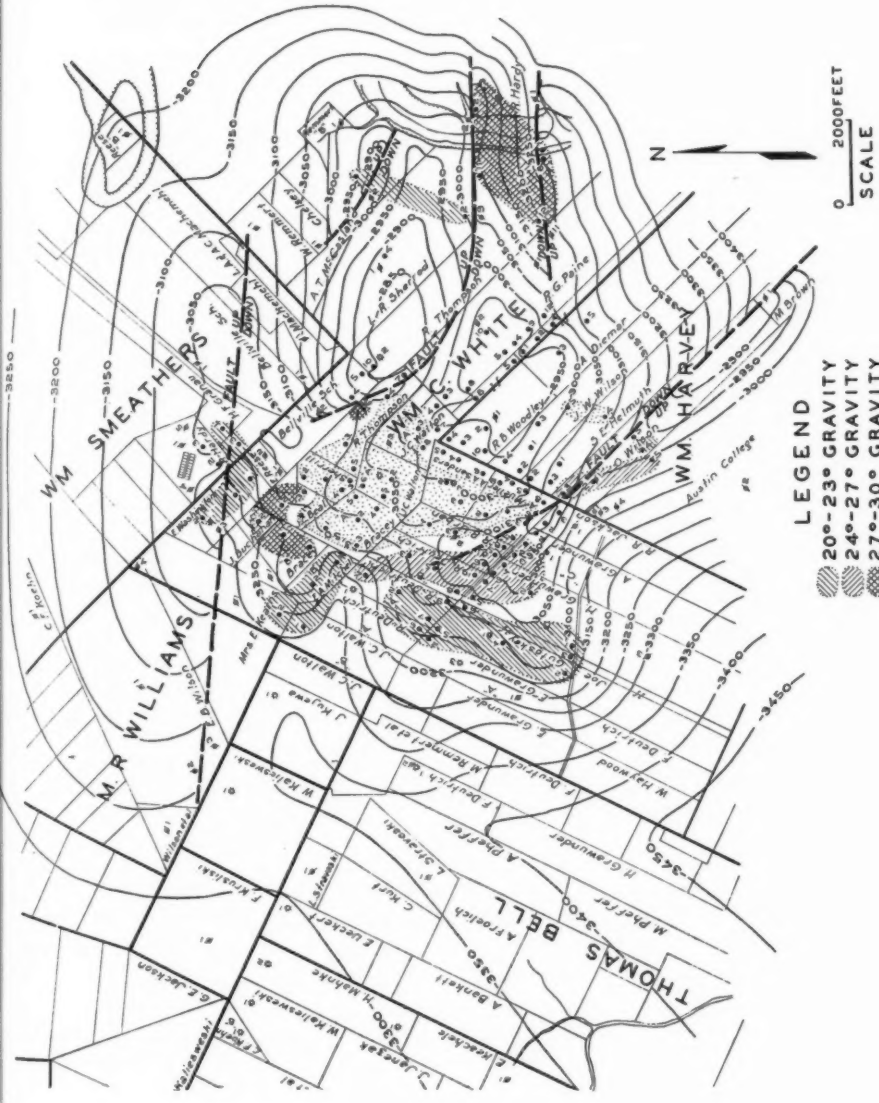

FIG. 6.—Map of Raccoon Bend field showing areas of similar oil gravities in the Gutoskey sand.

their distinctive oils cut across structural contours. The 23° Bé. gravity area at the west edge of the field is located structurally 150 feet, or half of the total amount of productive closure, below areas producing oils having gravities 5°–10° Bé. lower.

It might also be argued, but with less reason, if it is assumed that the oil formed at a distance from the dome, that the lighter components, naturally, by faster travel through the sands and sandy shales, had reached the dome first and occupied the higher sand lenses. As heavier products arrived later, they might have arranged themselves in turn in the next lower lenses until the supply of oil ran out. But the fundamental differences in the oils, other than gravity differences, as suggested by the analyses, do not favor this view, but point to indigenous origin.

Another explanation for the marked variation in the gravities of the oil in the Raccoon Bend field is offered by G. W. Jackson. He suggests that the amount of gas dissolved in the oil in each of the lenses is variable, and that lenses having relatively large amounts of gas have oil of relatively high gravity. The basis for this reasoning is the fact that during the past 3 years of gas injection at Raccoon Bend there have been drops in the gravity of the oil in some of the wells. It appears that 46 wells in those areas which have had gas injected

TABLE II

RELATION OF ORIGINAL GAS-OIL RATIOS TO OIL GRAVITIES
(GUTOSKEY SAND)

Well	*Non-Repressured Areas* *Average Gas-Oil Ratio*	*Average Oil Gravity*
A. T. McCasland 1	Very small	20.3
Washington A-2	Very small	17.6
Sherrod 2	170	23.3
Deutrich A-4	1,000	27.3
Gutoskey 4	210	21.3
Grawunder B-2	448	
	Repressured Areas	
Bracey A-4	1,136	31.0
Urban 3	235	31.0
Mueller 2	733	32
Thompson 5	270	30.6

RELATION OF ORIGINAL GAS-OIL RATIOS TO OIL GRAVITIES
(GRAWUNDER SAND)

Well	*Gas-Oil Ratio*	*Gravity* *Original*	*Present*
Grawunder C-1	180	28	22.9
Bellville School 2	Very small	26.6	24.6
Helmuth 2		31.6	28.7
J. W. Wilson 4	2,254	32.2	31.2
Ollie Wilson 3	3,300	26.0	
Sherrod 4	115	22.8	22.6
Sanders	775	31.0	30.3

the longest, or have had a greater volume of gas injected, show an average decrease in their gravities of 2° Bé., whereas, in 37 wells that have not had the benefit of repressuring, the average gravity drop has been 2.5° Bé. However, the repressured wells have been in areas less affected by water, the average water content being 16 per cent in those wells, whereas the non-repressured wells show an average water content of 35 per cent. Perhaps the large water content may have had some effect in causing the greater gravity declines.

A complete study of the relation of the original gas-oil ratios of wells in certain areas to the gravity of the oil in these areas is not possible (Table II), as detailed records of the gas ratios have not been kept since the inception of the field; however, in the wells that were studied, it is true that the areas of originally higher gas ratios were in general attended by oils of relatively high gravity. Of course the source material which we postulate accounted for the different gravities might also have accounted for the greater amounts of gas. If we had only differences in gravity to explain, the injection of gas into various sand lenses might more readily be accepted to account for the gravity differences. Whether or not differences in the oil, apart from the gravity differences which, it is true, are not so clear cut, could be explained by variable amounts of gas in the various lenses, is an open question. So little is really known about the factors that produce different types of oil, and the effects of earth changes on oil, that it is beyond the scope of this paper to do more than state the problem.

It has also been suggested[9] that the waters which had greater or less amounts of sulphates accompanying the oil in the various lenses, may have had greater or less oxidizing qualities, which would produce inherent gravity differences. This explanation for gravity differences within a field was advanced by G. Sherburne Rogers[10] in his account of the San Joaquin Valley oil fields in California. Table III shows analyses of water accompanying the oil in several lenses, together with the gravity of the oil in the respective lenses. Of 36 water samples from as many wells, a comparison of the sulphur content with the gravity of the attendant oil gives little basis for establishing the effect of the sulphates in the water. It is difficult also to point out from these analyses any other water constituent that might account for the gravity differences.

It is possible that all three of the explanations offered here to account for the variable oil gravities, namely, (1) variation in source

[9] John L. Rich, oral communication.

[10] "Chemical Relations of the Oil Field Waters in San Joaquin Valley, California," *U. S. Geol. Survey Bull. 653* (1917) p. 102.

TABLE III

ANALYSES OF WATER ACCOMPANYING THE OIL AT RACCOON BEND

(Chemical Constituents of Water in Parts Per Million)

Well	*Sand Depth*	*Original Gravity*	*Total Solids*	*Na.*	*Ca.*	*Mg.*	*Cl.*	*SO_4*	*Bicarb.*	*Sand*
Bellville School 4	3,432	26.6	22,483	7,940	224	77	13,400	—	842	Both sands
Bellville School 5	3,386	26.6	27,645	9,997	490	160	16,400	None	598	Grawunder
Buchanan 1	3,492	26.9	25,300	9,190	508	98	15,100	99	305	Gutoskey
Deutrich A-2	3,317	32.0	27,512	9,370	665	148	17,000	—	329	Gutoskey
Deutrich A-7	3,325	21.2	28,563	9,760	668	141	17,560	—	434	Gutoskey
Deutrich 2	3,259	28.2	30,881	11,368	439	164	18,600	None	310	Gutoskey
Gutoskey 2	3,282	23.0	26,923	9,500	794	120	16,240	123	146	Gutoskey
Gutoskey 3	3,267	23.0	32,818	11,550	958	168	19,660	206	276	Gutoskey
Gutoskey 4	3,280	21.3	29,264	9,890	835	199	18,100	—	240	Gutoskey
Grawunder B-1	3,230	22.5	24,946	8,670	908	126	15,150	78	14	Gutoskey
Grawunder B-7	3,230	24.7	30,323	10,586	806	275	18,400	None	256	Gutoskey
Grawunder C-2	3,410	24	30,814	11,460	716	153	18,020	—	466	Grawunder
Hardy 4	3,240	15	23,119	8,080	708	116	13,850	54	311	Gutoskey
Hardy B-2	3,202	30	24,060	8,985	342	50	14,500	None	183	Gutoskey
Helmuth 3	3,535	30.9	825	164	34	41	220	None	366	Grawunder
Jackson 1	3,530	26	24,033	8,650	515	109	14,200	132	427	Grawunder
Jackson 2	3,385	25.8	32,540	11,663	1,622	233	19,400	None	1,622	Grawunder
Jackson 3	3,379	25.4	31,217	11,200	556	141	18,600	None	720	Grawunder
McCasland 1	3,120	20.3	22,128	8,013	263	193	13,000	None	659	Gutoskey
Mueller 3	3,407	26.5	31,829	11,468	600	200	19,000	None	561	Grawunder
Paine 9	3,446	32.6	29,277	10,506	259	85	14,700	None	3,727	Grawunder
Paine 12	3,417	29.0	25,552	8,961	259	94	12,200	None	4,038	Grawunder
Sherrod 2	3,157	23.3	24,465	9,141	247	99	14,600	None	378	Gutoskey
Sherrod 4	3,381	22.8	27,645	10,196	250	90	15,500	None	1,610	Grawunder
Thompson 5	3,523	30.6	40,963	14,951	635	227	24,400	None	750	Gutoskey
Thompson 6	3,430	27.2	29,430	11,115	136	87	17,000	None	1,092	Gutoskey
Urban 6	3,212	26.1	526	49	85	21	170	None	201	Gutoskey
Washington A-2	3,253	14.3	23,751	8,050	580	166	14,440	315	200	Gutoskey
Washington B-1	3,433	21.2	29,706	10,741	538	127	17,300	Trace	1,000	Gutoskey

material, (2) variation in the amount of accompanying gas, and (3) the character of the associated waters, may have operated to produce the variable gravities and the variable characteristics of the Gutoskey oils.

Grawunder sand.—On the other hand, the accumulation of oil in the Grawunder sand corresponds very closely with the structural contours. The variation in the water level from the same structural contour in horizontal distance around this oil area is not more than a few hundred feet, and structurally not more than 20 feet. Continuity of the oil sand probably accounts for this.

In the case of the Grawunder sand the gravity of the oil is constant. There is one rather striking variation, however, on the south side of the field, where the south fault cuts across the south end of the Mueller tract, and the north end of the Grawunder C lease. The Grawunder sand oil north of this fault has a uniform gravity of 30°–31° Bé. Four wells on the south side of the fault in the Grawunder sand originally produced oil of 26°–28° Bé. The evidence indicates that the Grawunder sand is essentially continuous, affording a connected reservoir for the oil resulting in a uniform grade prior to faulting. After faulting the higher or gassy part of the dome was separated in this area from the flank or less gassy areas. As time went on the small amount of gas in the faulted flank, as well as the proximity of this part to water, may have reduced the gravity of the oil, while the gravity of the oil in the structurally higher area, then very effectively cut off by the fault, had its gravity increased by the greater amount of gas associated with the oil. Such an explanation is hardly possible for the Gutoskey sand because several lenses having distinctly different oils occur within an area having no known faults. It is also found in the Gutoskey sand that oils of the same gravity may occur in juxtaposition on either side of a fault which has cut a sand lense.

Bellville School Nos. 5 and 6 also show gravities of only 26° Bé., but in these wells both sands were screened so that mingling of two oil types resulted. The ease of repressuring throughout the extent of the Grawunder sand further reflects its uniformity.

HISTORICAL GEOLOGY

Little is known of the Raccoon Bend structure prior to McElroy time because only 3 wells have passed through the McElroy near the productive area, and 2 of these cut faults. However, owing to the extent of the structural influence of the dome, and the fact that its intensity increases downward from the surface, according to available data, recurrent structural movement was probably in progress even

before McElroy time. Although the normal McElroy thickness of about 600 feet persists around the dome, there has been little opportunity to learn its thickness at the apex because only one well could have passed through it normally (Bellville School No. 1), and the samples from this well have been lost. Much better sand conditions in the Grawunder horizon over the dome compared with its development in wells off the structure such as Humble, Hagen No. 1, E. B. Wilson No. 1, and Lamp No. 1, or Arkansas Fuel Oil Company, Machemehl No. 1, 10 miles west (Table IV) point to structural movement during McElroy time which induced faster currents and consequently permitted coarser deposits over the dome. Perhaps some of the 300-foot reduction in the thickness of the McElroy in Humble, Minnie Brown No. 1, which cut the south fault within 1,500 feet of proved territory, is due to shoaling, or post-McElroy erosion. In Humble, McCasland No. 2, the McElroy section has sustained a reduction of at least 214 feet because of faulting. From other data in wells on the northwest it is inferred that this reduction is caused by faulting rather than by truncation.

In Humble, Grawunder No. C-1, and C-2, and Jackson No. 2 the Grawunder sand lies only 215 feet below the top of the McElroy instead of 280 feet. Although this may be a horizon a little above the usual Grawunder sand, as the lower gravity of the oil suggests, it is possible that this reduced interval is due to post-McElroy truncation.

During Whitsett time, movement both upward and downward is apparent. The upward movement is indicated by the shoaling at the beginning of Whitsett time (*Massilina pratti* zone) that because of swifter currents improved the basal sand over the dome as compared with its normal development in off-dome wells, and reduced the normal thickness of this zone by 15–20 per cent. Before the end of Whitsett time, however, faulting was initiated which caused deeper water over the central part of the dome, or in the graben areas, resulting in an abnormally thick accumulation of Whitsett muds. It is immaterial whether the grabens were formed by subsidence of these areas or by greater uplift of the surrounding areas; the result is the same: a relatively depressed central area. The total thickness of the Whitsett in the main graben ranges from 250 to 333 feet, averaging 261 feet as compared with an average of 186 feet out of the grabens but on the structure, and an average in normal areas off the structure ranging from 225 to 300 feet. Faulting to the amount of at least 75 feet is therefore inferred during Whitsett time. Due to thinning of the section on the high parts of the structure, it is presumed that the general upward movement of the dome continued during most of Whitsett

TABLE IV

COMPARISON OF FORMATION THICKNESSES AND SAND CONTENT AT RACOON BEND WITH NORMAL SECTIONS

Formation	*Raccoon Bend Field*					*Normal Sections**												
	Thickness in Feet		Average Amount of Sand in Feet	No. of Wells Used		Thickness in Feet							Amount of Sand in Feet					
	Graben	Out of Graben		Graben	Out of Graben	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Vicksburg	191	156	40	8	3	215+	200?	240	?	250+	211	198	75	45	20	10	20	35†	40
Whitsett	261	186	47	17	14	210	210	274	190	245	230	240	27‡	16	30	80	7	55‡	20
Whitsett above *M. pratti* zone	181	109	30	10	4	110	125	124	90	125	130	130	13†	3	0	40†	0	35†	0
M. pratti zone (Gutoskey sand)	80	77	17	10	4	100	85	100	100	100	100	110	14	13†	30	40†	7	20	20
Grawunder sand (McElroy)			18	36									13†	3	0	0	10	0	0

* Explanation of numerals used in Table IV and distance from center of field.

1. Cranfill and Reynolds, Lewis No. 1, Austin County, 10 miles southwest.
2. Bunte *et al.*, Dittert No. 1, Austin County, 12 miles southwest.
3. Arkansas Natural Gas, Machemehl No. 1, Austin County, 8 miles west (up dip).
4. Bunte *et al.*, Harris No. 1, Waller County, 9 miles northeast.
5. H.O. & R. Co., Lamp No. 1, Austin County, 5 miles south.
6. H.O. & R. Co., Hagen No. 1, Austin County, 3 miles south.
7. H.O. & R. Co., Reese No. B-1, Austin County, 2¼ miles north.

† Sandy shale.
‡ Sand and sandy shale.

time and into succeeding Vicksburg and Frio time. Although these intervals are based on examination of samples from many wells, due to loss of samples, or due to the fact that sufficient samples were not taken, relatively few of the total wells drilled have been used. However, the wells that were used had complete sections and the conclusions arrived at here are believed to be very definite and dependable.

The thickening of the Whitsett seems to be confined to that part above the *Massilina pratti* zone, as an average of many well sections shows a thickness of about 77 feet out of the graben, and 80 feet in the graben for this zone, which is a little less than the normal thickness (100 feet) of this zone in normal areas.

During Vicksburg and Frio time the faulting initiated in the later part of Whitsett time continued as the thickening of the Vicksburg in the graben shows. The Vicksburg and Frio average 191 feet in the main graben and only 156 on the higher sides of the graben so that differential faulting movement of at least 35 feet during Vicksburg time is inferred. A reduction of the Vicksburg below normal on the high parts of the dome is also noted, suggesting upward movement during Vicksburg and Frio times outside the graben areas.

There is also a fairly continuous sand bed at the base of the Catahoula, which can be followed from well to well with fair accuracy. However, this sand has only been faulted down about 50 feet so that during basal Catahoula time some faulting and uplift were still in progress. The basal Catahoula sand is also arched, but the amount of its uplift is much less than that of the Jackson beds below. Apparently by early Catahoula time more than three-fourths of the uplift and faulting revealed on the structure had been completed.

During later Catahoula, Oakville, and Lagarto time some slight doming was in progress, as the less pronounced Oakville sand structure at 1,000 feet indicates, but the faulting seems to have been practically ended before the close of Catahoula time, for no faults are discernible in the Oakville sand.

AGE OF OIL ACCUMULATION

If the evidence submitted to show that much of the faulting at Raccoon Bend must have occurred during late Whitsett time and during basal Vicksburg time because of thickening in excess of normal of these sections, is tenable, then the age of this faulting, or at least a great part of it, must be rather definitely dated. Now it is also believed that the faulting post-dated the accumulation of oil in the sands in this field. If this is true, then the oil must have entered the

Gutoskey sand at least within a relatively short period after the deposition of this sand. The length of this period may be judged by the time required to deposit 250 feet of Whitsett and probably not more than 200 feet of Vicksburg. The reasons for believing that the faulting post-dated the oil accumulation are as follows. 1. When an individual sand lense is cut by a fault, oil of the same gravity and type is found on either side of the fault, indicating that the oil previous to faulting continued uninterruptedly through the lense and across the site of the fault. This is the case where the north fault cuts the Hardy-Reese-Buchanan area in the north part of the field. 2. In wells that have reached the producing horizon close to fault planes, the sand is found to be indurated and squeezed and, although it appears to be saturated with oil, it does not give up this oil, and a dry hole ordinarily results. The inference is that the oil entered and occupied the reservoir prior to faulting. In the Gutoskey sand, the various sand lenses with their different water levels and gas-oil levels prevent any conclusions respecting the age of the faulting from these standpoints, but in the Grawunder sand such conclusions are reasonable. In this sand the reservoir is continuous, so that the water level was substantially the same throughout prior to faulting. This is suggested by the fact that the water level now around the periphery of the Grawunder area is practically the same everywhere. However, in the low central areas, water has not been found even as much as 200 feet below the water level on the edges. Had the oil entered the Grawunder sand after faulting, one would suppose that either the water level would be the same both within and without the grabens, indicating communication and equilibrium across the fault planes, or else, if there were no such communication, one would suppose that the low central area would certainly have a water level at least as high as that on the edges, and that even though this feature were lacking, the water levels around the producing area, on various sides of the graben, would vary instead of being practically identical.

Therefore it seems probable in the Grawunder sand as well, from the evidence it has supplied, that the oil also has accumulated prior to faulting. The exact date can not be recognized so closely as it was with the Gutoskey sand, but it must have occurred within the same period required for the accumulation of the Whitsett oil plus the time needed to deposit the upper 280 feet of McElroy, or roughly during the time required for the deposition of about 725 feet of strata as compared, in the case of the Gutoskey sand, with the time needed to deposit only 445 feet of sediments.

As a matter of fact, the oil probably came in much sooner in both

sands, after the deposition of the reservoir, than the maximum time limits here outlined indicate. If there is any truth in the view that the different types of oil at Raccoon Bend are due to local differences in source material adjacent to individual lenses, the oil, in some early form at least, must have entered the sand almost immediately after the deposition of the sand.

GENERAL PRODUCTION DATA

The ordinary average initial production of the wells was about 450 barrels daily, flowing through a ½-inch choke. There are now (August 17, 1933) only 5 wells flowing out of 82 producing wells. Twelve other wells are shut in to keep the production within the Railroad Commission's field allowable of 4,500 barrels daily, and 20 wells are used for gas injection purposes, making a total of 114 completed wells in the field. The gas content has generally increased with the life of the well. The gas-oil ratio in the early stages of the field (1929) was 1,000, but it increased to 1,800 early in 1932 and is now 1,657. The gas ratios of the Grawunder sand wells are ordinarily higher than those of the Gutoskey sand wells.

The Raccoon Bend field to date (August 17, 1933) has produced 11,412,000 barrels, or 9,820 barrels per proved acre, or 514 barrels per proved acre-foot. As several wells are screened through both sands, the production from each sand can not be accurately estimated. Twenty-one Gutoskey sand leases, however, show an average acre yield to March 18, 1933, both by leases and total acres, of 6,700 barrels for this sand, and 8 Grawunder leases show 13,570 barrels per acre for the average lease for that sand, or 10,780 barrels for the average acre. This is about 400 and 600 barrels per acre-foot, respectively, for these two sands. If this production is distributed over the total productive and possibly productive area, which amounts to 1,700 acres, there has been an acre-yield to August 17, 1933, of 6,770 barrels, or 376 barrels per acre-foot. Seventy-one wells have produced from the Gutoskey sand, 36 from the Grawunder sand, and 7 are screened through both sands (Fig. 7).

Pressure maintenance.—To maintain the reservoir pressure and to assist in the movement of the oil toward the wells, high pressure gas has been injected into both sands since July 27, 1930. The effect of this injection is undoubtedly good, because the decline curves of a number of leases have perceptibly flattened and even risen from their normal slopes. Although the original pressures in the upper sand were variable, they averaged respectively about 1,000 pounds and 1,250 pounds in the upper and lower sands. To-day the bottom-hole pres-

sures of the wells in the Whitsett sand range from 300 pounds to 1,000 pounds, due probably to variable pressures built up in separate Whitsett lenses by gas injection.

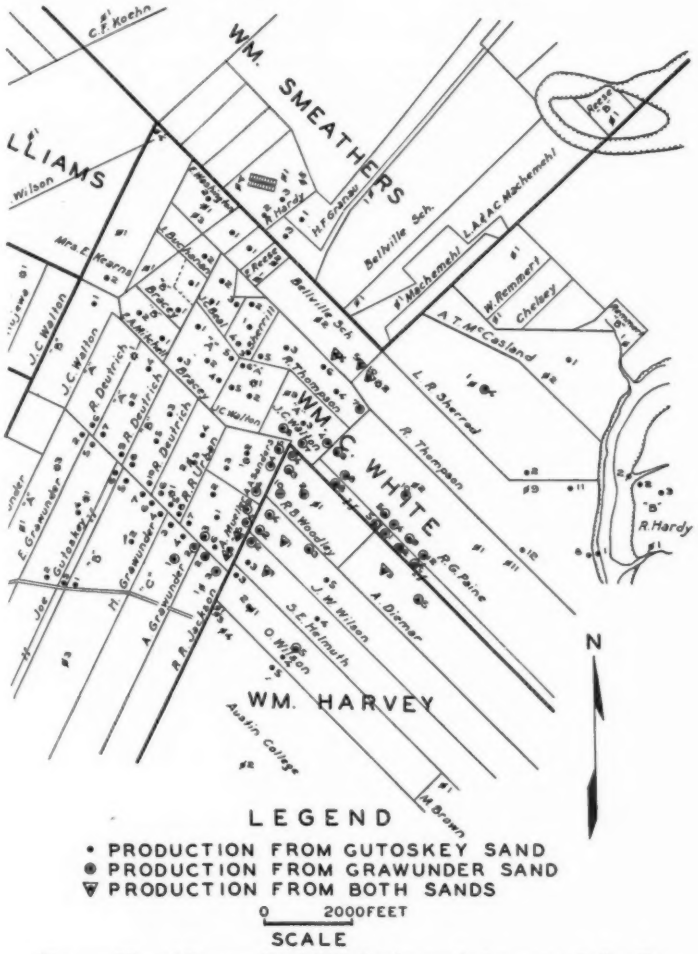

FIG. 7.—Map of Raccoon Bend field showing producing zones of oil wells.

A total of 5,122 million cubic feet of gas have been injected into both sands through July, 1933, by means of key wells, or 49.5 per cent of the total gas produced since repressuring was commenced.

The key wells are being constantly changed as experience shows the need. Due to the lenticular condition of the Whitsett sand, 13 key wells are required for its gas injection and beneficial results are not so apparent as in the more continuous, evenly distributed Grawunder sand. Seven key wells inject gas into the Grawunder sand. During the past year or so, 1,295 million cubic feet of gas, apparently without loss, have been stored for future use in the eastern end of the 1,000-foot gas sand reservoir, so that 61.8 per cent of the total gas produced in the field from all sands has been returned to some sand. The gas stored in the shallow sand is being withdrawn when needed for local uses.

Currently the following disposition of the gas at Raccoon Bend is made daily.

	Cubic Feet
Injection to oil zones	4,174,000
Plant and field fuel	1,949,000
Sold to M. & M. Co., for commercial uses	685,000
Stored in 1,000-foot sand	997,000
Total	7,805,000

The field is daily producing about 8 million cubic feet of gas, so that less than 200,000 cubic feet is going to the atmosphere, or 3 per cent of the total gas produced.

The injection of gas is accomplished by 24 compressors, totalling 2,400 horse-power. The compression is in three stages. The gas comes from the wells at 2 inches vacuum and it is then raised to 35 pounds and then to 150 pounds, and from that point to 300 pounds, 1,000 pounds, or 1,200 pounds, depending on the location of injection. The gas going into the Gutoskey sand is raised to 800 pounds or more and that to the Grawunder sand is injected at 1,200 pounds. Along with the compression of the gas, about 7,700 gallons of casing-head gasoline are produced daily which is run into the pipe-line with the oil.

Completion of wells and oil production.—The usual method of completion of the Raccoon Bend wells is to set 7-inch O. D. casing close to the sand to be tested. In 19 wells, 9-inch casing was set to provide for later deepening, but in the past 3 years only 7-inch casing has been set. The sand section is cored solidly, as the absolute necessity for careful coring in the Jackson sand lenses is realized. Drill-stem tests are used to some extent, but it is preferable to set pipe and test whenever there is a reasonable excuse.

In wells producing from both sands, of which there are 15, screen settings up to 350 feet are made. The usual setting in one sand, though, is about 20 feet. Two-inch or 2½-inch tubing is set in the well and production is obtained through the tubing. All gas is metered.

The wells are operated by either individual Lufkin units (59 wells) or a generator plant which runs 7 wells. One power is in operation for a group of 11 wells, because the average yield of this group is only 19 barrels, or too small for individual operation. The pumping wells average 52 barrels each, and their total production is 4,000 barrels. Currently 4,500 barrels daily are produced with about 6.5 million cubic feet of gas, or an average yield of 58 barrels per well. There are 5 flowing wells out of a total of 82 wells now producing. The total daily yield of the flowing wells is 529 barrels, or an average of 106 barrels each. Approximately 49 per cent of the fluid raised is oil. The field is operated solely by the Humble Oil and Refining Company.

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OVERHANGING SALT ON DOMES OF TEXAS AND LOUISIANA[1]

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ABSTRACT

Overhanging salt has been found on eleven coastal and interior domes in Texas and Louisiana. The first ledge of salt drilled through was at Belle Isle, Louisiana, in 1898; the first oil produced from formations beneath salt was found at Anse la Butte, Louisiana, in 1902. However, oil was not extensively and prolifically produced until discovery of the overhanging at Barbers Hill in 1930.

The general theories for the cause of overhangs are reviewed. The present criteria for the advance recognition of overhangs are listed, and the probability of other overhangs is conjectured. The special methods required for drilling through cap-rock cavities and salt are described.

The known overhangs are described and general and specific examples are shown by cross sections.

A tabulation shows wells drilled through salt overhangs.

ACKNOWLEDGMENTS

Much of the information used in the present paper was beyond the direct personal observation of the writers, because of the period of time involved and the large number of domes studied. Therefore, much information has been used from many papers by Gulf Coast writers. Operators have freely extended the use of their records and many geologists have supplied essential information and suggestions. John Larke, of the Texas Gulf Producing Company, has collaborated in the collection, preparation, and study of this information and has made the drawings of the figures used.

INTRODUCTION

Purpose.—Oil in small quantities was produced from sedimentary beds beneath a salt overhang at Anse la Butte, Louisiana, as early as 1902. Records do not show that any great significance was attached to the discovery at that time, and in general the appearance of salt in a well, even though it could be drilled through, was then regarded as unfavorable. Expressing the opinion of that time, Fenneman[4] in

[1] Presented before the Houston meeting of the Association, March 23, 1933. Manuscript received, September 18, 1933.

[2] Chief geologist, Texas Gulf Producing Company.

[3] Geologist, Texas Gulf Producing Company.

[4] N. M. Fenneman, "Oil Fields of the Texas-Louisiana Gulf Coast," *U. S. Geol. Survey Bull 260* (1904), pp. 459–67.

1904 wrote: "In general, experience has not been favorable to the finding of oil beneath the salt."

This exploration at Anse la Butte led to similar exploration at Vinton where several wells were obtained beneath a salt overhang. The difficulty of such exploration and the disappointing results secured discouraged exploration of this type for many years. However, with the extensive development of oil sands discovered in 1930 beneath an overhang of salt at Barbers Hill followed by similar development at High Island and Lake Barre, sufficient interest, it is believed, has been directed to the study of known overhangs and possible overhangs on salt domes to justify the collection and presentation of available data concerning them.

Definition.—The term "salt overhang" is construed in this paper to mean a body or ledge of salt attached to, and protruding outward from, the central mass of a salt dome.

GEOLOGIC FEATURES OF TYPICAL SALT OVERHANG

A typical shallow overhang is shown in Figure 1(a). This is a generalization of the conditions found in the overhang on the east flank at Barbers Hill, where sufficient exploration has been made to give a detailed picture of such a condition. This overhang was described in detail by Judson, Murphy, and Stamey.[5] This is considered typical of a shallow overhang where a thick cap rock above the salt rests on the salt and in places extends 200 or 300 feet beyond it. The three characteristic zones are shown, namely, the cap rock, the salt, and the gouge zone.

The cap rock is composed in downward order of: (1) an upper false cap of calcareous sandstone of variable thickness which was formed by the almost complete calcareous cementation of the loose sands overlying the true cap rock; (2) a zone composed of calcite intermixed with sedimentary beds by collapse of the cap rock; generally porous and cavernous and ranging from a few feet to 200 feet in thickness; (3) a relatively thin member of calcite and gypsum which contains the largest caverns of the cap rock; and (4) a basal member of massive anhydrite; in places minor cavities are found at the contact of this anhydrite with the salt below.

The composition of the salt in an overhang is ordinarily identical with that of the salt of the main dome. The impurities, which range approximately from 2 to 20 per cent, consist largely of anhydrite

[5] Sidney A. Judson, P. C. Murphy, and R. A. Stamey, "Overhanging Cap Rock and Salt at Barbers Hill, Chambers County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 5 (May, 1932), pp. 469–82.

crystals disseminated through the salt. These impurities as found in salt cores from many widely separated domes were discussed in a paper by Hanna.[6] A few irregular, steeply dipping beds consisting principally of anhydrite sand several hundred feet in thickness are found within the salt. Material from adjacent sedimentary beds also occurs interspersed through the salt. The thickness of the salt penetrated varies from a few hundred feet at the outer edge of the overhang to 2,800 feet, the greatest thickness drilled at present.

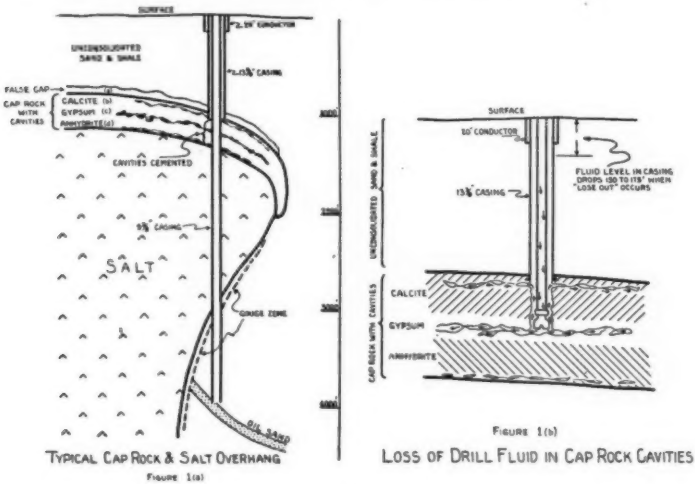

FIG. 1

The gouge zone, ordinarily about 50 feet thick, occurs between the salt and the sedimentary formations below the overhang. This zone is composed of anhydrite sand which remains as a residue from the solution of the salt, mixed with salty shale, fragments of massive anhydrite, quartz sand, and shale, some of which is richly fossiliferous.

DISTRIBUTION

Eleven of the salt domes of Texas and Louisiana have been found to have salt overhangs. Of these domes five are in the Gulf Coastal Plain of Texas, namely, Hull, Barbers Hill, Allen, High Island, and Orchard; four in the Gulf Coastal Plain of Louisiana, namely, Anse la Butte, Belle Isle, Vinton, and Lake Barre; and two in the interior,

[6] Marcus A. Hanna, "Secondary Salt-Dome Materials of Coastal Plain of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (November, 1930), pp. 1469–75.

namely, Keechi and Bethel, which are in the East Texas geosyncline. The writers have found no records of salt overhangs on the domes in the interior of Louisiana. The locations of the salt domes with known overhangs are shown in Figure 2.

It is of interest that the greatest number of overhangs have been found on domes of the Gulf Coastal Plain, the region where the formations penetrated are more recent and accordingly less consolidated than those farther inland.

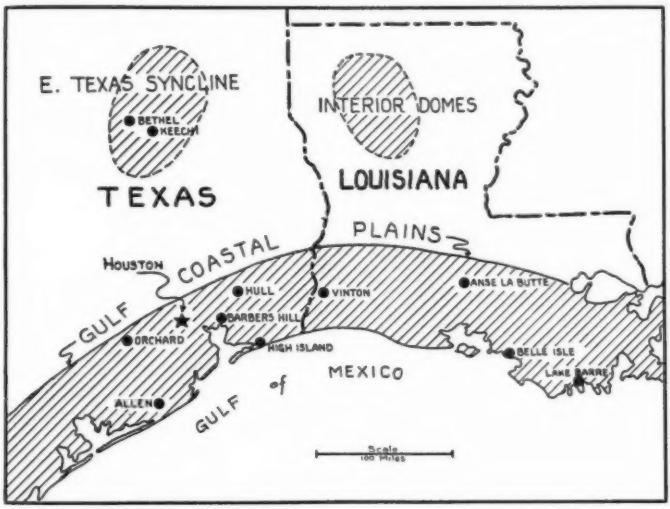

FIG. 2.—Location of salt domes with known overhangs.

HISTORY

The history of the discovery of salt overhangs extends through 35 years, from the year 1898 to the present.

FIRST PERIOD (1898–1930)

A considerable number of early attempts were made to drill through the salt in the hope of finding oil sands beneath. The results were discouraging because the overhangs discovered yielded little oil. This period of unprofitable exploration lasted from the year 1898 to 1930. During this time exploration of the salt gradually diminished because of the great difficulty encountered in completing wells through overhangs. At the end of this period it was generally believed that it was impossible to drill through the salt excepting in a few places; therefore it was unwise to attempt it.

Overhangs were found on the following domes in the order named: Belle Isle (1898), Anse la Butte (1902), Vinton (1911), Keechi (1917), Hull (1922), and Bethel (1929).

Attention was first drawn to the probability of the existence of an overhang as early as 1898, when a well drilled on the flank of the dome at Belle Isle was reported to have gone through three separate beds of salt alternating with sedimentary formations. It was finally abandoned in salt. The first instance of a well encountering a definite overhang was at Anse la Butte in 1902, when the Haywood No. 1 was recorded as making a small producing well beneath 272 feet of salt. No cap rock was found above the salt.

Vinton, Louisiana, can claim the first known example of an overhang in which oil was produced from formations beneath both cap rock and salt. Overhangs were later discovered at Keechi, Hull, and Bethel, but the first two are believed to be small, and the extent of the one at Bethel has not been defined by drilling.

SECOND PERIOD (1930–1933)

The discovery of oil in large quantity beneath the overhanging salt at Barbers Hill, Texas, in February, 1930, marked the beginning of the period of purposeful exploration of domes for possible overhangs. This development stimulated study and exploration of other coastal salt domes to determine whether or not they also had overhangs with oil beneath. This drilling resulted in finding that High Island, Allen, and Orchard in Texas, and Lake Barre in Louisiana, were domes of the overhang type. The date of discovery of salt overhang on these domes follows: Barbers Hill, Texas (1930), High Island, Texas (1931), Allen, Texas (1931), Lake Barre, Louisiana (1931), and Orchard, Texas (1932).

Prolific wells have been developed beneath the overhang at High Island and Lake Barre, but Allen and Orchard have not yet been sufficiently explored to determine whether or not worth-while oil deposits lie beneath the overhangs. Unsuccessful attempts to discover overhangs have been made on several domes. Noteworthy examples are those at Sulphur, Louisiana, and at Fanette dome and Damon Mound in Texas.

CAUSES OF SALT OVERHANGS

Three general theories of the cause of overhangs were reviewed by Judson, Murphy, and Stamey in their description of the overhang at Barbers Hill.[7] The writers of that paper state first the theory of the

[7] Sidney A. Judson, P. C. Murphy, and R. A. Stamey, *op. cit.*

outward movement of salt where in its upward flow it meets the resistance of thick heavy cap rock on the top of the dome. The thick cap rocks present at Vinton, Hull, Barbers Hill, Allen, and High Island suggest that on these domes the upward flow of salt was interrupted by heavy cap rock and turned outward, thus aiding in producing the present overhangs.

The second theory stated in the paper mentioned was quoted directly from Barton.[8] This theory predicates that under certain conditions,

> (1) the main mass of the salt core tends to remain fixed in earth space and therefore at a constant depth below the surface if the surface remains at a constant level, and (2) that the base of the salt core builds downward by flowage of salt in under the base of the salt core. . . . The final form should be that of an inverted elongate tear drop.

It is believed that overhangs caused according to this theory would be deeper than the greatest depth to which the salt has been explored by drilling.

The third theory in the paper quoted was set forth by Hanna.[9] This theory portrays the solution of the salt below the cap rock by both artesian waters and water pressed out of the shale by compaction. The forces producing overhang of this type would be at their maximum where the top of the dome is protected from the circulating waters by a thick cap rock, massive where in contact with the salt, but porous in its outer surface, permitting the upward movement of water through channels and crevices well away from the salt.

Barton[10] has recently proposed the following.

> [1] Two types of overhang presumably are present in the Gulf Coast.
>
> Tilting of the axis of the salt core of several domes is surmised by the writer from geologic and gravity data. For commercial reasons the data may not be presented at this time. They are scanty and not conclusive; yet from them, the writer surmises that tilting of the vertical axis of the salt core must be present. On the dome on which the data are most conclusive, the overhang would seem to be on the side away from the gulf and the gentle slope on the side toward the gulf.
>
> The overhang at Barbers Hill goes essentially around the dome, and the upper part of the salt-cap core has somewhat the form of a mushroom.
>
> Overhang of the upper part of the salt-cap core could be produced in several ways.
>
> Dynamic overthrusting has slightly overturned many of the salt domes of old Roumania, but can not explain the overhang in the Gulf Coast.

[8] Private communication of Donald C. Barton.

[9] Marcus A. Hanna, *op. cit.*

[10] D. C. Barton, "Mechanics of Formation of Salt Domes with Special Reference to Gulf Coast Salt Domes of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 9 (September, 1933), pp. 1025–83.

Tilting of the axis of the salt core could be produced as the effect of flowage of the prism of unconsolidated sediments toward the unsupported edge of the continental shelf. This flowage should take place partly as an effect of the static pressure of the upper sediments on the lower sediments and, therefore, should be greater at moderate depth than at the surface. The salt core should move with the surrounding sediments; and the upper part of the salt core should move less than the part at moderate depth.

Barton also suggests in a private communication the following possible causes.

[2] The static weight of a massive anhydrite cap on the top of a static salt core might push down and thicken the upper part of the salt core. This explanation doubtfully could explain so much overhang as that at Barbers Hill.

[3] Pseudo-overhang, caused by slabs of salt or salt plus cap being sheared off and side-tracked at the edge of the dome.

The overhangs at Belle Isle and Anse la Butte apparently were caused by circulating waters. The overhangs on the six other domes where heavy cap rock is present are certainly caused in part by this action. In fact such solution in greater or lesser amounts must be going on in all the domes of Texas and Louisiana and tends to produce overhangs wherever the upper part of the salt is protected by a cap rock and the salt below it is exposed to the dissolving action of circulating waters.

ADVANCE DETECTION OF OVERHANGS

The methods so far developed that have been of aid in determining in advance whether or not a dome has overhanging salt, consist of geophysical or geological subsurface studies, or both. The methods employed vary with the information already obtained from wells drilled on, or immediately adjacent to, the dome. If adequate drilling information is absent, geophysical methods making use principally of torsion-balance or seismic surveys are employed.

GEOPHYSICAL METHODS

Torsion-balance surveys are made which consist of lines radial from the center of the dome with closely spaced stations across the dome and extending outward from it several miles. Studies made by geophysicists indicate that the presence of an overhang of the Barbers Hill type and magnitude can be determined in advance by such surveys.

The seismic methods are divided into three classes.

1. Refraction methods of shooting, using both short and very long shots across the dome, permit separate computations of the approxi-

mate diameter of the dome, both near the surface and at considerable depth. This method allows the detection of an overhang only where the diameter of the upper part of a shallow dome greatly exceeds that existing at a greater depth. This method was first suggested by C. G. Rosaire[11] in 1929.

2. A seismic-reflection method for detection of an overhang was developed by the Geophysical Research Corporation and was described by Lester.[12] This consists of the determination of the position of a steeply dipping bed lying against the salt at considerable depth by reflections nearly perpendicular to the bed. By proper selection of shot points and detector stations this bed can be traced to a point approaching its limit against the salt beneath an overhang. The outer limit of the suspected overhang can then be determined either from well records or by seismic-reflection methods, and from these data the presence and approximate magnitude of the overhang can be found.

3. A method is described by McCollum and LaRue[13] in which detectors are lowered into a deep well adjacent to the salt. Shot points are used at the surface above the salt on both the opposite and adjacent flanks, and also near the well. This method permits the close delineation of the salt section adjacent to the well.

It is reliably reported that all of the torsion-balance and seismic methods here listed have been used either to discover an overhang or to delineate further one already known to exist.

GEOLOGIC SUBSURFACE STUDIES

Interpretation of geologic data obtained from wells reaching the dome close to its outer edge and from deep wells immediately adjacent to the salt, is often of much aid in judging the probability of the presence of an overhang. These studies resolve themselves into three classes.

1. One method of interpretation is a study of the vertical cross section of a salt dome where sufficient data from wells exist to give some clue to the probability of the existence of an overhang. The surfaces of some domes slope outward to a point where the dip increases so abruptly that deep wells slightly farther out fail to encounter the salt. These domes are fair "prospects" for further work

[11] Oral communication.

[12] Read before the Society of Petroleum Geophysicists at Houston, November, 1930.

[13] Burton McCollum and Wilton W. LaRue, "Utilization of Existing Wells in Seismograph Work," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 12 (December, 1931), pp. 1409–17.

in searching for an overhang. When a considerable projection of overhanging cap rock extending outward from a dome is found by drilling, the presence of a salt overhang also is strongly suggested.

2. A study of dips of sedimentary beds as determined from cores and cross sections from wells near a dome is of aid in estimating the comparative distance, at various depths, of a well from the salt mass. The principle involved is that dips around salt domes generally become steeper as the salt is approached. Accordingly, steep dips at shallow depths followed by gently dipping beds at greater depths are suggestive of an overhang.

3. The amount and character of secondary mineralization of the adjacent sedimentary beds give a slight clue to the relative distance, at different depths, of a well from the dome, because some beds contain higher mineralization nearer the dome. Studies of such mineralization are helpful in estimating the extent of an overhang, but must be used with caution because the amount of mineralization is also affected by other factors, including radial faults commonly present on the flanks of salt domes.

PHYSIOGRAPHIC STUDIES

Topographic features, such as a circumferential ridge lying directly above or just inside the position of the outer edge of the salt mass, may in a few places suggest the presence of a salt overhang. Barton[14] in 1930 called attention to ridges of this type at Barbers Hill and Vinton. Topographic maps of these two domes are shown in Figures 9 and 5. It is of interest to note that a circumferential ridge occurs at Barbers Hill on the flanks where the salt overhang is shallow, but is missing on the flank where the overhang is comparatively deep. Anse la Butte also has a central basin surrounded by a low ridge. The remaining eight domes listed as having overhangs do not have circumferential ridges suggestive of an overhang.

Physiographic features are in general so affected by other forces that the presence or absence of an overhang can not be determined from topography alone. Physiography can be made use of as a suggestion only in judging the presence of an overhang.

SPECIAL DRILLING METHODS REQUIRED

The rotary drilling methods usually employed in unconsolidated formations are modified in practice to meet the special conditions presented by the overhang. Such methods were described in detail by

[14] Discussion by Donald C. Barton, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), p. 741.

Williams,[15] Logan,[16] and Judson and Battle.[17] The principal difficulties to be overcome are caused by the natural caverns in the cap rock and by the solution caverns commonly formed in the salt by drilling.

The principal problem in the cap rock occurs when drilling fluid is lost in its porous zones. Due to the low hydrostatic head existing in these cavities, the drilling fluid flows into the canvernous parts of the cap rock and no longer returns to the surface, or, in the language of the driller, a "lose-out" occurs. This is illustrated in Figure 1(b). These cavernous zones are so extensive that several million barrels of drilling fluid and water have been pumped into the cap rock of a single dome without greatly increasing the hydrostatic head in the cavernous zone. When returns are lost there is much danger of the drill pipe "sticking" due to the unconsolidated formations above the cap rock falling into the hole as the fluid level quickly lowers. Such fishing jobs can ordinarily be avoided by a close examination, by a geologist, of the cuttings from the well every few feet directly above the expected position of the top of the calcite zone of the cap rock so that casing can be set at nearly the exact top of the cap rock. This practice permits drilling to proceed through the cap rock even though the drilling fluid escapes into the cavities, since the casing cuts off the unconsolidated formations that tend most readily to cave into the hole. The usual practice when encountering the cavernous zone in the cap rock is to fill the cavities or loose sands with cement. A mixture composed of ordinary cement to which has been added a relatively small part of bentonitic compound or other chemicals to increase its "angle of repose" is pumped into the hole in sufficient quantities to fill the cavities immediately surrounding the drill hole. This process is repeated as needed. Another method used is to set and cement a short liner through the cavernous zone.

When the salt is encountered, extremely large solution caverns may be dissolved out in the salt if fresh-water drilling fluid is continued in use. These caverns tend to produce crooked holes and may cause extremely difficult fishing jobs. This condition is avoided by using a supersaturated salt solution in place of the fresh-water drilling fluid. As drilling is continued through the salt, in order to prevent an accumulation of salt cuttings in the bottom of the hole which would interfere with further drilling, it is customary to add continuously

[15] Neil Williams, "New Practices in Going Through Cavities in Salt Domes Reduce Coastal Drilling Costs," *Oil and Gas Jour.*, Vol. 31, No. 5 (June 20, 1932), pp. 49–50.

[16] Jack Logan, "Advanced Drilling Methods Used in Gulf Coast Operations," *Oil Weekly*, Vol. 68, No. 1 (December 19, 1932), p. 21.

[17] Sidney A. Judson and J. C. Battle, "Special Methods Required to Drill Through Overhanging Cap Rock and Salt," *Oil Weekly*, Vol. 69, No. 1 (March 20, 1933), pp. 59–62.

small amounts of fresh water to the drilling fluid to dissolve these cuttings. In any event, an attempt is made to keep the drilling fluid of such a composition that an excessive amount of salt cuttings will not remain in the bottom of the hole, but will be dissolved without enlarging the hole above to an excessive size.

Frequent well surveys are necessary to detect an excessively crooked hole, which ordinarily occurs while drilling in salt. These crooks are usually corrected by cementing back to where the "crook" begins and then redrilling the hole cautiously. When this method fails, the hole can be enlarged by drilling with fresh water while reaming, to form a cavern in which the bit will swing into a vertical position because of gravity. The hole is then drilled ahead with only a little weight on the bit.

In general the difficult drilling conditions occuring in the cap rock and salt are so varied as to require the greatest resourcefulness and ingenuity on the part of the operator. However, improvement of drilling methods through cap rock and salt has been given much attention in the last two or three years by chemical and petroleum engineers and by field organizations, with the result that these operations are rapidly being improved.

PROBABILITY OF EXISTENCE OF OVERHANGS ON OTHER DOMES

The probable number of domes that will later be found to have overhangs can be estimated by comparing the number of domes explored for overhangs with the number of overhangs discovered. Approximately 112 domes are known to exist in the salt-dome provinces of Texas and Louisiana. Of these, approximately 18 shallow domes that seemed most probably to have overhangs have had at least partial exploration for such a condition. This exploration has been usually confined to the particular flank of a dome that seemed to the operator most probably to have an overhang. As a result of this drilling, 11 overhangs have been found, although, with the exception of Barbers Hill, High Island, and Vinton, it is unknown whether these are extensive overhangs or merely small ledges of salt. Accordingly, it will be seen that by the exploration of 16 per cent of the total number of domes, 11 overhangs have been discovered, or approximately 70 per cent of the total number of domes explored. It is believed that this percentage will be too high for the total number of domes. However, this exploration has been so meager compared with the total number of domes that there is insufficient basis for making more than a mere guess as to the total number of known domes that will finally be found to have overhangs.

It is probable that a considerable variation exists in the type of overhangs that will be found, depending on the presence or absence of a thick cap rock covering the top of the salt dome. It is believed that a thick cap rock not only acts as a sheath to protect the upper part of the salt dome from solution by circulating waters, while at the same time the part of the salt below the cap rock is relatively exposed to attack by solution, but that a thick cap rock also tends to create outward flowage of the salt because of its resistance to the upward movement of the salt on account of the higher specific gravity of the cap rock. Thus overhangs of considerable magnitude and extent might reasonably be expected to be mostly confined to those domes where thick cap rocks are present. Conversely, the domes where cap rock is absent would probably have overhangs only in the nature of ledges formed from local "pitting" of the salt face because of water-bearing beds coming in contact with the salt.

On account of the greater freedom of circulation of water at relatively shallow depths, it is believed that extensive overhangs much more probably exist within 4,000 feet of the surface than would be expected below that point and still within present drilling depths. That is, overhangs of the largest size will most probably be found in the shallow-dome class. This does not take into consideration extensive overhangs that may occur far below the depth of present wells where the weight of the overlying prism of sediments is much greater than the weight of a corresponding prism of the salt, with the result that the diameter of the salt plug at these greater depths may be diminished by the squeezing action upon the salt by the surrounding sedimentary formations.

DOMES IN GULF COASTAL PLAIN OF LOUISIANA

BELLE ISLE

Belle Isle salt dome, the southernmost of the "Five Islands," is in St. Mary Parish on the edge of Atchafalaya Bay of the Gulf of Mexico. A detailed description of this dome with full references to previous literature is given by Vaughan.[18] The results of a later torsion-balance survey and subsequent drilling are discussed by Barton.[19]

Belle Isle rises out of the marshes to a maximum of 80 feet in the series of low hills which cover the western part of the dome. This ex-

[18] Francis Edward Vaughan, "The Five Islands, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 4 (July, 1925), pp. 783–94.

[19] Donald C. Barton, "Belle Isle Torsion-Balance Survey, St. Mary Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 11 (November, 1931), pp. 1335–50.

ceptional topographic rise above a coastal salt dome indicates recent upward movement of the dome. The topography is not suggestive of overhanging salt.

This dome is oval in plan, its longer axis being approximately 1.4 miles in length at a depth of 1,000 feet. It is extremely shallow, salt being found in one well within 117 feet of the surface.

Drilling operations were begun here in 1896 and since that time between 30 and 35 tests have been drilled in exploration for oil or sulphur. These, with a few exceptions, were shallow holes above the salt. The flanks of the salt have been only partly defined. Showings of oil, gas, and sulphur were reported, but these minerals have not been developed in commercial quantities.

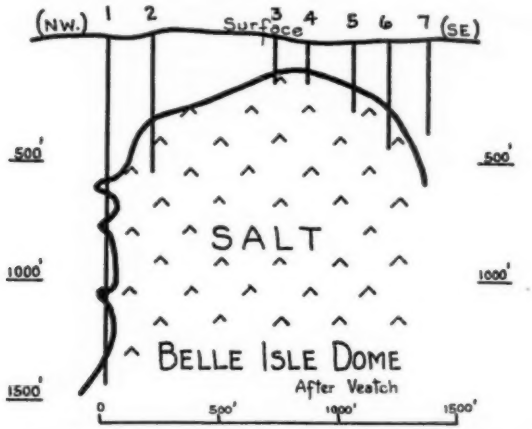

FIG. 3.—Belle Isle dome. 1. Gulf No. 5. 2. Gulf No. 1. 3. Gulf No. 12. 4. Mine shaft. 5. Gulf No. 10. 6. Lucas No. 4. 7. Gulf No. 14.

Overhang. A succession of salt ledges were found in Gulf No. 15, which was drilled during the year 1898. This well was shown in a cross section by Veatch[20] as having passed through three small ledges of salt alternating with other formations between the depths of 600 and 1,100 feet. None of these salt ledges exceeded 30 feet in thickness. The drill went into salt again at approximately 1,350 feet and the hole was abandoned in salt at approximately 1,500 feet. It appears from a study of the accompanying cross section after Veatch (Fig. 3) that these small projections of salt extending outward into probably sedimentary beds do not constitute a well defined salt overhang of the

[20] A. C. Veatch, "The Five Islands," *Geol. Survey of Louisiana Rept. for 1899*, pp. 209–57.

type found at Anse la Butte, Vinton, and Barbers Hill, but the condition as pictured at Belle Isle comes definitely within the terms of the definition of salt overhangs.

Knapp No. 1, drilled in the year 1907 or 1908 near the center of the dome, seems to have been an attempt to drill through the salt in search for oil in sedimentary formations beneath, because it was drilled in salt from a depth of 200 feet to 3,171 feet, an extraordinary amount of salt penetration for that time. This test must be classed as one of the exceptional explorations of this type, particularly if the stage of development of drilling methods at that time be considered. No wells other than the Gulf No. 15 are reported to have been drilled through a salt ledge on this dome.

The top of the salt at Belle Isle was found to contain pockets of sediments resembling those of the surrounding formations. Though the amount of these impurities lessened with increasing depth, thin bodies of sedimentary formations were recorded even near the center of the plug at a considerable depth in the salt. Several showings of oil and gas in these sediments were recorded. Sedimentary inclusions of this sort, existing well within the salt plug proper, are not considered to be salt overhangs.

ANSE LA BUTTE

Anse la Butte salt dome is in St. Martin's Parish, Louisiana, approximately 60 miles northwest of Belle Isle. Its early development is described by Harris,[21] Hayes and Kennedy,[22] and Fenneman.[23] The surface above the dome rises 10 feet higher than the surrounding territory. A lake has formed in a central basin directly over the shallow salt which here rises to within approximately 100 feet of the surface. The upper part of the dome consists of a spine of salt of less than ½ mile in diameter protruding up from the probable main salt mass whose top is found at a depth of approximately 5,000 feet. This spine of salt has no extensive cap rock, although cap rock 150 feet in thickness is found on the top of the main salt body. Figure 4 is a cross section illustrating this interesting condition.

This dome was one of the first salt domes on which oil development was begun. The first producing well was drilled in 1902. Ap-

[21] G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Survey Bull. 429* (1910), p. 34.

[22] C. W. Hayes and William Kennedy, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *U. S. Geol. Survey Bull. 212* (1903), p. 130.

[23] N. M. Fenneman, "Oil Fields of Texas-Louisiana Gulf Coastal Plain," *U. S. Geol. Survey Bull. 282* (1906), pp. 105–10.

proximately 30 of the 100 tests drilled have been producing wells from shallow flank sands around the salt spine. A few wells were large producers, but the total recovery to date amounts to only approximately 1,000,000 barrels.

Overhang.—On this dome is the first known oil well of commercial size producing from beneath an overhang of salt. The Heywood No. 1 on the north flank of the salt spine was recorded by Fenneman as having passed through salt from 268 to 540 feet into sands and clays

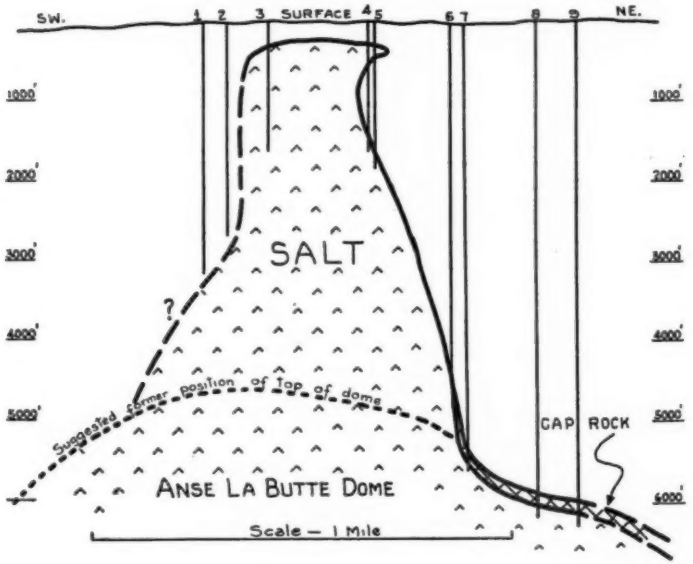

FIG. 4.—Anse la Butte dome. 1, 2. Humble-Moresi Nos. 5, 3. 3, 4. Heywood Martin Nos. (?), 1. 5. Anse la Butte Begnaud No. 2. 6, 7, 8, 9. Yount Lee-Louisiana Petroleum Company's Nos. 3, 5; Herbert Nos. 1, 2.

and back into salt at 1,350 feet. This well, drilled in 1902, was a 40-barrel producer from a depth of 1,100 feet. This discovery of a salt overhang in the early days of salt-dome exploration is noteworthy because it shows that the early pioneers of salt-dome drilling believed that oil might be present beneath the salt. Two other wells are known to have been drilled through the salt overhang, one on the north flank and the other on the east flank of the salt spine, but neither was an important producer. It is believed that this overhang of salt is of small extent and probably of little importance commercially.

VINTON SALT DOME

Vinton, in the extreme western part of the coastal plain of Louisiana in Calcasieu Parish, is fully described by Thompson and Eichelberger.[24] The surface over the dome is 25 feet higher than the surrounding surface and, like Belle Isle, has a central basin in which a lake has formed.

The topography is illustrated in Figure 5. This is a dome of the shallow type, with the top of the salt lying generally just below the 1,000-foot level. The nearly circular salt plug has a diameter of 3,700

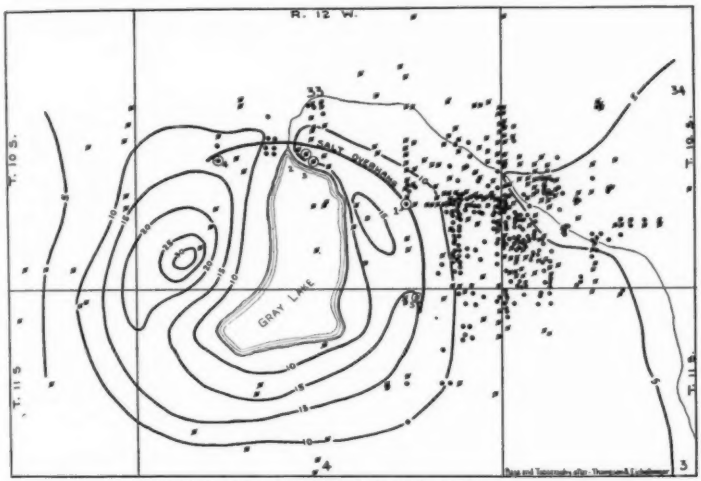

FIG. 5.

feet at the 3,000-foot level and is overlain by a thick body of cap rock which is 400 feet thick in the center of the dome, increasing to 750 feet on the north flank. The form of the cap and the suggested shape of the salt mass are illustrated by the south-north cross section of Figure 6, after Thompson and Eichelberger. The extraordinary wave-like rise of the deep salt shown on the north flank between Gulf Refining Company's Gray No. 1 and Gray No. 2 may be due to crooked holes.[25]

Vinton was the first of the salt domes to produce flank oil.

[24] S. A. Thompson and O. H. Eichelberger, "Vinton Salt Dome, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 4 (April, 1928), pp. 385–94.

[25] S. A. Thompson, Private communication.

Exploration for oil was begun in 1901, but it was not until 1910 that the first flowing well was completed. Development after this was rapid. This field has produced more than 38 million barrels of oil principally from flank sands in a zone extending outward from the salt ½ mile on the east flank. Approximately 600 wells were drilled, of which 400 were producers.

Overhang.—The success at Anse la Butte in finding sedimentary beds containing some oil under a salt overhang prompted the operators at Vinton to explore for a similar overhang here, hoping that they might find large wells beneath.

As early as 1911 the Gulf-Wilson No. 1 on the northeast flank was drilled through cap rock from 975 to 1,106 feet, salt 1,106 to 1,140 feet,

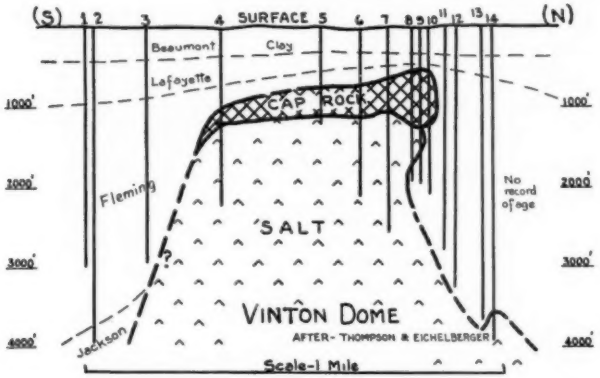

FIG. 6.—Vinton dome. 1. Ged Petroleum Company's Gray No. 1. 2. The Texas Company's Gray No. B-1. 3. Stark Trust's Gray No. 1. 4. The Texas Company's Gray No. 1. 5. Carter Oil Company's Gray No. 1. 6. The Texas Company's Brooks and Bettis No. 1. 7. Supreme Oil Company's Gray No. 2. 8, 9, 10, 11, 12. Marrs McLean's Gray Nos. 3, 1, 4, 6, 5. 13, 14. Gulf Refining Company's Gray Nos. 1, 2.

gypsum 1,140 to 1,170 feet, and salt 1,170 to 1,413 feet. It was drilled into sedimentary beds to a total depth of 2,100 feet, where the well was completed with a daily production of 20 barrels. Later, three wells on the north flank and one on the east flank have been drilled through overhanging cap rock and salt. These tests show an overhang approximately one third of the distance around the periphery of the dome (Fig. 5) on the north and east flanks, although more exploration is necessary to determine how far this may extend. The cap rock overhang extends a short distance beyond the salt overhang. The width of the overhang has not been defined by drilling, although on the north flank it is known to be at least 200 feet wide.

Approximately 1 million barrels of oil has been produced from beneath the salt and cap-rock overhangs. However, it is probable that several exploratory tests will be required to determine whether extensive deposits of oil are present beneath the overhang.

LAKE BARRE

Lake Barre salt dome is in Terrebonne Parish, Louisiana, close to the Gulf of Mexico. It lies under water, with the exception of a few marsh islands. It was discovered by a seismic survey in 1928.

Exploration was begun in March, 1929, and the presence of the dome was proved when The Texas Company's State Lake Barre No. 1 was drilled into cap rock and salt. The same company's Lake Barre No. 2 was completed in September, 1929, on the northeast flank of the dome, at a total depth of 3,850 feet, with an initial production of 5,000 barrels oil per day through an open line. This well produced 1,200 barrels when later pinched to a $\frac{3}{8}$-inch choke. Development has been orderly due to the fact that one company has control of the entire dome. Twenty-five wells have been drilled on the east and northeast flanks and nearly all have been completed as large flowing producers. Approximately $5\frac{1}{2}$ million barrels of oil have been recovered up to April 1, 1933.

Overhang.—The Texas Company's State Lake Barre No. 6, completed in July, 1931, on the northeast flank, passed through 12 feet of salt and anhydrite from 3,036 to 3,048 feet and went into sedimentary beds below. This suggestion of an overhang was confirmed when State Lake Barre No. 12 on the north flank drilled through 286 feet of salt from 2,522 to 2,808 feet, where sedimentary beds were again encountered. This well was completed as a 2,700-barrel well at a total depth of 3,809 feet. Two other wells are recorded as having passed through salt ledges: the State Lake Barre No. 14 went through two ledges of salt, and State Lake Barre No. 16 found four salt ledges. The overhang is illustrated in Figure 7. The protruding extensions of salt are nearly all covered on their upper slope by an outer sheath of cap rock which rendered these ledges less subject to solution by circulating waters than lower surfaces of the salt where generally a relatively thin covering of cap rock exists, if present at all.

This overhang of salt has been shown by drilling to extend for a distance of 1,800 feet along the northeast flank of the dome, with its limits undefined in either direction along the dome. The lack of wells inward toward the center of the dome from the outer edge of the salt projection leaves the radial extent of the overhang unknown. The exceptionally large number of thin salt ledges encountered suggests

that the condition here is similar to the salt ledges at Belle Isle rather than to the well developed type of overhang found at Vinton and Barbers Hill.

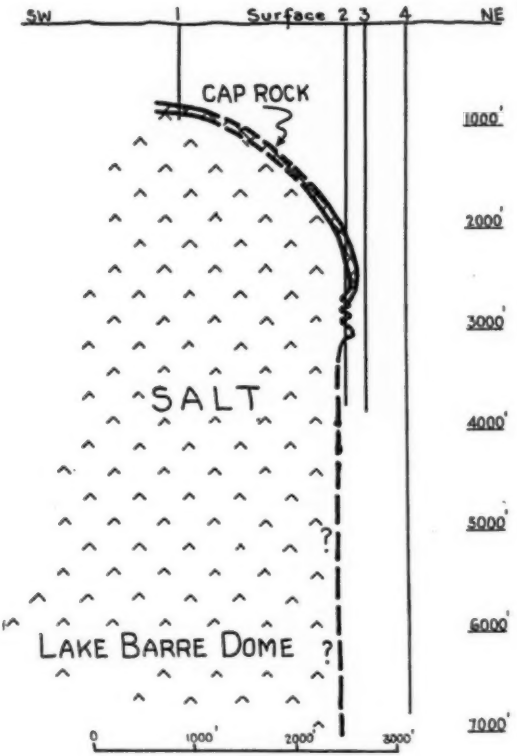

FIGURE 7

FIG. 7.—Lake Barre dome. 1. The Texas Company's Lake Barre No. 1. 2, 3, 4. The Texas Company's State Lake Barre Nos. 16, 4, 8.

DOMES IN GULF COASTAL PLAIN OF TEXAS

HULL

Hull salt dome is in Liberty County about 50 miles northeast of Houston. The low but distinct circular mound on the surface closely coincides with the location of the underlying salt dome.

This dome is of the shallow type. The dome is nearly circular and has a diameter of about 1.25 miles at the 2,000-foot salt level. Cap

rock was found at a depth of 285 feet and salt at 595 feet in a well near the center of the dome. A considerable thickness of cap rock lies above the salt. The larger part of the top of the salt is found above the 1,000-foot contour.

This was proved to be a salt dome by the Sun Oil Company in 1908, when shallow cap rock and salt were found in drilling. Ten years elapsed, however, before oil was discovered. Then the Republic Company's Fee No. 3 was completed, producing 1,000 barrels daily from a shallow flank sand at a depth of 1,200 feet. Exploration of flank sands proceeded rapidly and oil was ultimately produced on all flanks of the dome. More than 72 million barrels of oil have been produced from approximately 600 wells. The field is now producing 4,700 barrels daily (March, 1933).

Overhang.—An overhang of salt was recorded in June, 1922, in the Republic Production Company-Houston Oil Company's Dolbear Fee No. 55 on the northeast flank. Salt was penetrated from 1,190 feet to 1,454 feet and a 2,000-barrel well was completed in a sedimentary sand at a total depth of 1,955 feet. A second well near the first, the Dolbear No. 55-A, was completed 10 years later, in July, 1932. This well also found sedimentary beds beneath a salt overhang and was drilled deeper into what seems to be the main salt mass. The summary of the log in feet follows: cap rock from 745 to 1,263; salt to 1,665; cap rock to 1,714; sedimentary beds to 2,030; salt to 2,262.

This second well confirmed the presence of at least a local overhang. Though oil was produced from beds beneath the overhang in the first well, records do not show further development of this overhang and accordingly its extent is unknown, although further drilling suggests that the condition is confined to a small area.

HIGH ISLAND

High Island salt dome, in Galveston County on the shore of the Gulf of Mexico between Galveston and Sabine Pass, has been briefly described in previous papers; the very early history by Fenneman[26] and its recent development with particular reference to salt overhangs by Halbouty.[27]

The surface expression of the salt dome is a circular mound about 1.25 miles in diameter, rising at its highest point approximately 21 feet above the surrounding salt water marsh.

This is a shallow dome with cap rock recorded in early wells at

[26] N. M. Fenneman, *op. cit.*

[27] M. T. Halbouty, "High Island Dome, Galveston County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 7 (July, 1932), pp. 701–02.

depths ranging from 150 to 200 feet. Though only parts of the logs of the early wells on top of the dome were available to the writers, it appears from the meager data that this dome has a thick cap rock. The dome has been outlined in slightly more than half its circumference and is approximately 1.5 miles in diameter at the 3,000-foot cap-rock level.

Exploration of the cap rock was commenced soon after the discovery of oil at Spindletop in 1901, and although a little oil was discovered in a thin sand 150 feet in depth, it was as late as 1923 before oil was produced in important amounts from the flanks of the dome. Practically all of the oil has been produced from Miocene sands on the south and west flanks of the dome. The total flank production to date is 3 million barrels. The present daily production is 7,100 barrels.

Overhang.—The presence of a salt overhang was suggested in the year 1929, when the Gulf Production Company's George E. Smith No. 8 was drilled through salt from 3,282 to 3,327 feet. The formations for the next 127 feet were recorded as being principally of a sedimentary type, although on account of the absence of sufficient cores this is uncertain. The hole re-entered cap-rock material at 3,454 feet. However, the first well definitely to place High Island in the class of overhanging salt domes was the Yount Lee Cade No. 21, on the northwest flank. This well was drilled through salt from 4,777 to 4,821 feet and back into sands and shale. It made a 700-barrel producer from a total depth of 5,077 feet. Eight wells have been recorded as having been drilled through the salt overhang. Those on the west and northwest have shown the presence of a well developed salt overhang, and good flowing wells have been obtained beneath it.

A northwest-southeast cross section illustrating the overhang is shown in Figure 8. The overhang on the northwest flank has been found to extend, up to the present time, for 400 feet along the periphery of the dome. The width of this overhang is unknown because there are no deep wells located radially inward from the outer edge of the overhang. The presence of overhang on the south flank has been indicated by the log of the Yount Lee Fee (Mathis) No. 1, where 100 feet of shale was recorded beneath a body of 1,271 feet of salt.

Studies by Halbouty[28] indicate that it is probable that overhang will be found on all flanks of the dome.

Though this paper is limited to the description of salt overhangs to the virtual exclusion of cap-rock overhangs, it is of particular interest to note that a cap-rock overhang extending beyond the salt overhang is well developed on the northwest flank of this dome. This cap-rock

[28] Private communication.

overhang is really an adjunct of the salt overhang, the salt originally beneath it probably having been dissolved by circulating waters.

The present development of prolific oil sands beneath the overhang at High Island leads to the conclusion that a large amount of oil will be obtained from wells drilling through the overhang.

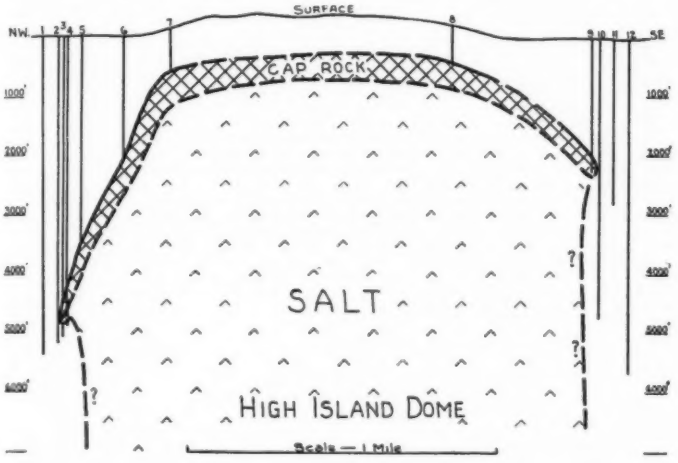

FIG. 8.—High Island dome. 1, 2, 3, 4. Yount Lee Oil Company's Cade Nos. 24, 22, 21, 23. 5, 6. Sun Oil Company's Cade No. 11, Guidry No. 1. 7. Yount Lee Oil Company's Guidry No. 1. 8. Patton Oil Company's Gordon No. 2. 9. Sun Oil Company's Cade No. C-9. 10. Marrs McLean's Cade No. C-6. 11. Patton and Robichaux' Cade No. 1. 12. Sun Oil Company's Cade No. C-8.

BARBERS HILL

Barbers Hill salt dome is in Chambers County, Texas, 27 miles northeast of Houston. The early history of this dome was written by Bevier[29] and the subsequent exploration of the flank sands was described by Murphy and Judson.[30] The presence of the dome is marked by a 40-foot elevation of the surface above the surrounding country. The topography is illustrated in Figure 9. This is a shallow dome and the top of the thick cap rock is found at 350 feet at its highest point. The top of the salt is at about 1,350 feet.

Patillo Higgins drilled the first test for oil in 1902, and proved the presence of the salt dome by finding cap rock. The first producing

[29] George M. Bevier, "Barbers Hill Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 6 (September, 1925), pp. 958–73.

[30] P. C. Murphy and S. A. Judson, "Deep Sand Development at Barbers Hill," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), pp. 719–41.

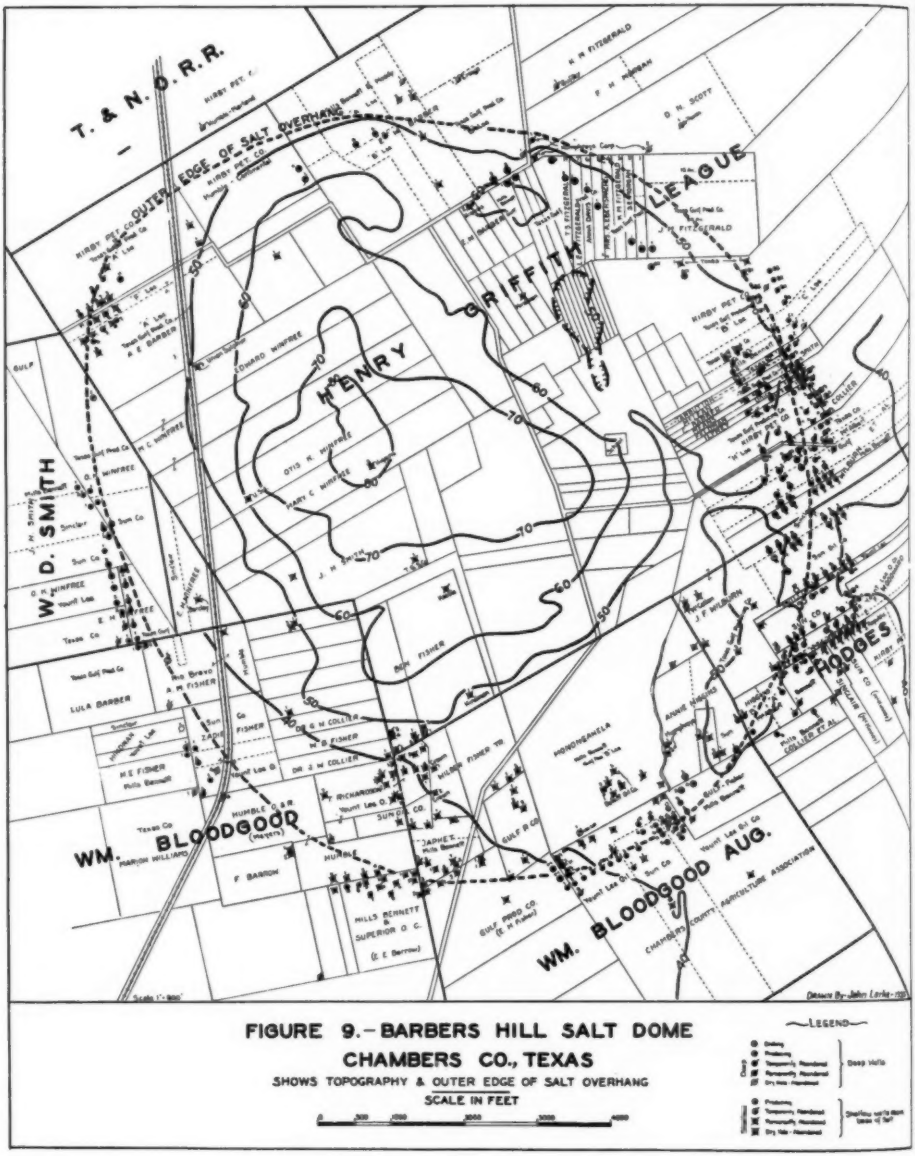
T. & N. O. R.R.
OUTER EDGE OF SALT OVERHANG
LEAGUE
GRIFFITH
HENRY
W. D. SMITH
WM. BLOODGOOD
WM. BLOODGOOD AUG.
HOOPES
BARBERS HILL SALT DOME
CHAMBERS CO., TEXAS
SHOWS TOPOGRAPHY & OUTER EDGE OF SALT OVERHANG
SCALE IN FEET
LEGEND

FIG. 9.

well was completed in 1916. Extensive development was not begun until 1929. Approximately 300 wells have produced 31,400,000 barrels of oil up to April 1, 1933, nearly all of this coming from flank sands.

Overhang.—The discovery of the salt overhang and the development of the oil sands beneath it up to February, 1932, were described in detail by Judson, Murphy, and Stamey.[31] Since that time 40 additional wells have been drilled through the overhang, making a total of 92 wells. Salt overhang has been proved on all flanks excepting the southwest, where exploration is inadequate to determine its presence.

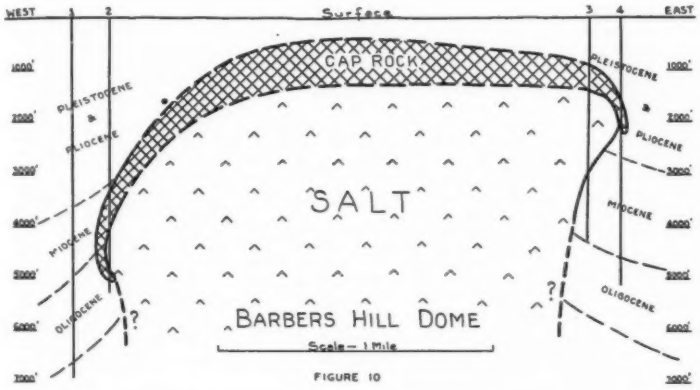

FIG. 10.—Barbers Hill dome. 1. The Texas Company's Marion-Williams No. 1. 2. Sun Oil Company's O. K. Winfree No. 2. 3, 4. The Texas Gulf Production Company's Kirby Nos. H-12, H-6.

An east-to-west cross section in Figure 10 illustrates the deep overhang on the west flank and the shallower but wider overhang on the east, where its width has been proved for at least 700 feet. The average thickness of salt drilled through in recent wells is about 1,600 feet. A few wells have been drilled through 2,800 feet of salt to develop production. The inner limit of the overhang at the 5,000-foot level has been reached in few wells, although sufficient control exists to estimate closely its approximate position.

The amount of oil obtained from beneath the salt overhang at Barbers Hill greatly exceeds that produced from beneath overhangs on any other dome. Approximately 12 million barrels of oil have been

[31] S. A. Judson, P. C. Murphy, and R. A. Stamey, "Overhanging Cap Rock and Salt at Barbers Hill," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 5 (May, 1932), pp. 469–82.

already produced from the wells drilled through the salt. It is expected that nearly all future oil recovered from the sands of Miocene and Oligocene age, the present producing formations, will be from wells drilled through the salt. Drilling adds continuously to the known reserves beneath the overhang.

ALLEN

Allen dome, in Brazoria County, Texas, is 60 miles southwest of Houston and approximately 8 miles inland from the Gulf of Mexico.

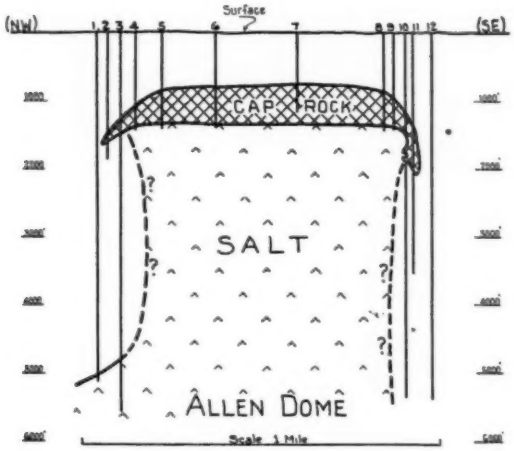

FIG. 11.—Allen dome. 1. Shell Petroleum Corporation's J. T. Reese No. 3. 2. Freeport Sulphur's J. T. Reese No. 2. 3. Mills Bennett Production Company's J. T. Reese No. 2. 4, 5, 6, 7, 8, 9. Freeport Sulphur's J. T. Reese Nos. 8, 6, 4, 15, 12, 7. 10, 11, 12. Mills Bennett Production Company's Randon *et al.* No. 2; Poole No. 1; Randon *et al.* No. 12.

The presence of this dome was indicated by a torsion-balance survey by the Shell Petroleum Company in 1925 and was confirmed when the same company in its initial test, Allen No. 1, on the east flank, encountered cap rock at 822 feet. This company in May, 1927, completed Bernard River No. 1 as the first producer, yielding 700 barrels of 31° gravity oil from a depth of 5,141 feet. Exploration for oil has been mainly confined to flank drilling. Thirty-nine wells have been drilled on the various flanks. Of these nine wells were producers. The total oil recovered has been 69,000 barrels. Additional drilling is necessary to determine whether or not the flank sands will provide attractive production.

The shape of this dome as indicated by drilling is circular, with a diameter of less than one mile.

Overhang.—Randon No. 2, on the southeast flank, drilled by Mills Bennett Production Company in 1931, is recorded as having penetrated alternating ledges of cap rock and salt, in feet, as follows: cap rock from 1,199 to 1,631; salt to 1,792; cap rock to 1,799; salt to 1,814; cap rock to 1,822. Sedimentary beds were found from 1,822 to 5,308 feet. Sands containing oil showings were found at 2,700 and 4,493 feet. The hole was abandoned at 5,308 feet because of a fishing job.

A northwest-southeast cross section of this dome is illustrated in Figure 11. Because of meager drilling data the width and extent of the salt overhang can not be reliably estimated.

ORCHARD

Orchard dome, in Fort Bend County, Texas, is 40 miles west and slightly south of Houston. It was located in 1924 by a seismic survey for the Gulf Production Company. Presence of the dome was proved in the same year when the Gulf Production Company's J. M. Moore No. 1 encountered cap rock at 375 feet. In January, 1926, the Gulf Production Company completed its John M. Moore No. 5 on the east flank, yielding 2,000 barrels of oil at a depth of 3,759 feet. Development of this dome is under control of one company, and the field has had an orderly drilling program. More than 1,800,000 barrels have been produced from 20 wells. Production so far developed has been located on the south and the northeast flanks of the dome.

Overhang.—The Gulf Production Company's Moore No. 34, on the southwest flank, was drilled through 76 feet of salt from 3,077 to 3,153 feet and continued in sedimentary strata to a depth of 4,389 feet, where it was abandoned after testing three sands below the salt, all of which produced either sulphur water or salt water. This well had a very thin cap rock above the salt and is the only well on this dome recorded as having passed through salt overhang. The lack of exploration of the overhang by further drilling leaves its extent a matter of conjecture.

SALT DOMES IN EAST TEXAS SYNCLINE

KEECHI

Keechi salt dome, in Anderson County, Texas, is 6 miles northwest of Palestine. This dome has been described in detail by Powers.[33]

[33] Sidney Powers, "Interior Salt Domes of Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 1 (January, 1926), pp. 35–45. *Ibid.*, *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), pp. 243–53.

He states that this dome did not produce a conspicuous topographic feature. The first exploration for oil at Keechi was in 1916 and 1917, when the Producers Oil Company (now The Texas Company) drilled five dry holes. Since that time a few additional tests have been drilled, principally by the Navarro Oil Company, although oil in commercial quantities was not discovered. This is a very shallow dome. Sixteen feet to 200 feet of cap rock is recorded in wells on the northwest flank. Its diameter is about 1½ miles at the 3,000-foot level, and appears to increase rapidly with depth.

Overhang.—One well was recorded by Powers[33] as having been drilled through a salt ledge. This was the Producers Oil Company No. 1, which was drilled through 660 feet of salt from 2,162 to 2,822 feet. Sands with heavy oil are recorded from 2,822 feet to 2,899 feet, and sandy shale from 2,899 feet to 3,091 feet. Salt was encountered again from 3,091 to 3,170 feet, where the well was abandoned. A cross

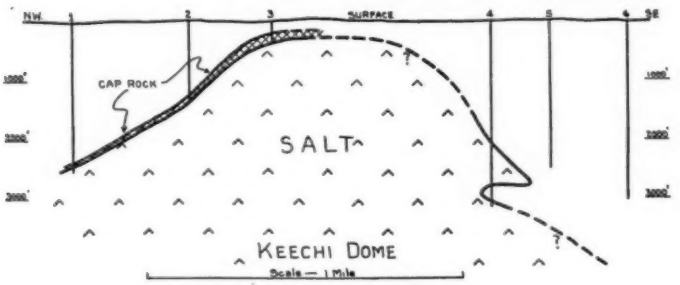

FIG. 12.—Keechi dome. 1, 2, 3. Navarro Oil Company's Greenwood Nos. 4, 3, 2. 4, 5, 6. Producers Oil Company's Barrett and Greenwood Nos. 1, 3, 5.

section from northwest to southeast across this dome, shown by Figure 12, after an illustration by Powers as modified by later drilling, indicates the shape of the salt mass and the salt ledge. This single instance of finding a short section of sedimentary beds beneath salt does not justify a conclusion that an extensive overhang exists here.

BETHEL

Bethel dome is in the extreme northwestern part of Anderson County, Texas, 14 miles northwest of the Keechi dome. It was located by a seismic survey and salt was found in the year 1928 at a depth of 1,600 feet beneath 110 feet of anhydrite. The development has been limited to a total of four exploratory wells, none of which was a producer.

Quarter	Lease	Salt Top	Overhang Base	Total Salt	Total Depth	Completed	Initial Prod.	Flush	Remarks
				MILLS DOME, LOUISIANA					
1. Gulf Company	Well #6 or #15(?)	600	650	50	1600'				
		780	810	30	1600'				
		1080	1100	20	Approx.	1926	Gas	FW	
				AVOCA LA DOME, LOUISIANA					
1. Heywood	Martin #1	868	920	52	1900'	1928	40	SW	Prod.from 1100'
2. Amo La Acita	Regional #2	893	963	130	1794'	?	Gas	S	
3. Martin-Simpson	Regional (?)	890	970	180	950'	?	Gas	S	
				VILTON DOME, LOUISIANA					
1. Gulf refining Co.,	Wilson #1	1330	1413	307	2190'	1911	40	SW	— Gypsum 1140-1170'
2. Harry Nolen	F. H. Gray #1	1358	1545	845	2300'	1922	Prod.	W	— Oil formations to 2000'. salt 2000-2200'
3. " "	F. H. Gray #3	1240	1730	540	1918'	-	Prod.	S	
4. Gulf Refining Co.,	F. H. Gray #4-A	1415	(?)	(?)	1948'	-	Prod.	S	
5. Freddeman	J. C. Gray #1	970	990	19	1630'	-	Gas	S	
6. Harry Nolen	F. H. Gray #10	1898	1435	235	1748'	-	Prod.	S	
7. Harry Nolen	F. H. Gray #12	1300	1545	245	2700	-	Prod.	S	Oil horizon 1700-200 Salt 2000-2700'
				LAKE HAYES DOME LOUISIANA					
1. Texas Company	Atgis Lake Barrel	3036	3048	12	3618'	1931	2100	SW	
2. " "	" " " #12	3822	3906	294	3809'	1932	700	S	
3. " "	" " " #14	1978	1112	34					
		3350	3384	34	3808'	1932	1978	S	
4. " "	" " " #16	3412	3380	230					
		3798	3780	43					
		3970	3994	24					
		3967	3982	185	3782'	1932	1788	S2	
				HULL DOME, TEXAS					
1. Republic Production Co.	Hullwar Fee #16	1190	1484	264	1918'	1928	4000	SW	
2. " "	" " #16-A	1645	1646	402	2018'	1928	Gas	S2	
				NEW LIBERTY DOME, TEXAS					
1. Gulf Production Co.,	G. H. Smith #6	3901	3947'	46	3494'	1929	Gas	S	
2. Yount Lee Oil Co.,	Cade #21	4077	4081	64	4077'	1931	700	SW	
3. " " " "	Cade #23	4631	4741	110	4758'	1931	Gas	SW	
4. " " " "	(Mac) Fee #2	4618	4938	317	4938'	1932	62	SW	
5. " " " "	Cade #28	4691	4738	47	4898'	1932	758	SW	
6. " " " "	Geo. H. Smith #13	3971	3973	190	4125'	1932	Gas	SW	Salt 3934-4480
7. " " " "	(H.Hatchie) Fee #1	3110	3138	28					
		3146	3215	71					
		3636	4007	1471	4008	1933	Gas	S	
8. " " " "	Cade #33	4723	4903	180	5015'	1933	1025	SW	
				RAGSDALE HILL DOME TEXAS					
1. Humphrys Corporation	Ilfrey #2	1535	2409	874	2087'	2/25/30	1062	W	
2. " "	Nolsen #1	2046	2293	247	2300'	2/22/30	1185	S	— Drilled to 2079' & Plugged back to 2260
3. " "	Morgan #1	2346	2542	196	6404'	6/25/30	319	WS	— Later deepened to 6469' & abandoned.
4. " "	Kirby #2-A	2194	2242	48	2234'	6/29/30	80	S	— Small pumper
5. Mills Bennett Prod., Co.,	Gulf-Fisher #8	2177	2433	256	4715'	7/12/30	1052	S	— Later deepened & completed at 4843'. Later deepened & completed at 4922'
6. Sun Oil Company	Chambers #9	2223	2273	330	4134'	9/22/30	1000	S	—
7. " " "	Wilburn Fee #9	2091	2171	30	2167'	9/19/30	186	WS	
8. Mills Bennett Prod., Co.,	R. S. Barber #3	1857	2196	1641	2147'	10/1/30	1460	S	
9. Humphreys Corporation	T. S. Fitzgerald #1	2115	2244	349	4367'	10/19/30	1900	WS	
10. Yount Lee Oil Company	Chambers #15	2238	2486	148	4733'	11/23/30	1320	S	— Later deepened & Completed at 5293'
11. Humphreys Corporation	Kirby #3-A	1631	2551	910	5295'	11/29/30	1930	S	
12. " "	Barber /A-6	2221	4360	779	5468'	12/16/30	942	SW	
13. Sun Oil Company	Wilburn Fee #12	2043	2285	242	5127'	12/18/30	900	WS	
14. Humphreys Corporation	R. S. Barber #3-1	2265	2721	636	4793'	12/26/30	None	WS	Stuck drill pipe.Abd.
15. Sun Oil Company	Chambers #7	1834	2030	1256	4683'	1/5/31	2018	S	
16. Mills Bennett Prod., Co.,	Gulf -Fisher #2	1467	2792	1325	4377'	1/22/31	1320	S	Deepened to 4656.flowi
17. Yount Lee Oil Company	Chambers #17	1633	2241	1880	5084'	2/2/31	180	S	
18. Humphreys Corporation	Kirby #10	2180	2346	318	6088'	2/20/31	None	SW	— Tested 5.W.W 6370' Abandoned @ 6968'
19. " " "	R. S. Fitzgerald #1	1484	2842	1821	5879'			WS	— Top Ind salt 4928'T.D. 5379'salt,5.2. 1700'
20. Yount Lee Oil Company	Chambers #18	1758	2283	1488	4465'	3/24/31	690	S	
21. Mills Bennett Prod., Co.,	S. F. Barber /3-1	1415	2113	1007	5260'	3/26/31	220	S	
22. Sun Oil Company	Chambers #8	1835	2198	1366	4821'	4/4/31	1100	S	
23. Humphreys Corporation	Barber /3-2	1.80	2239	1859	5079'	4/11/31	1662	WS	
24. " " "	J. F. Wilburn #6	1716	2097	298	5234'	4/24/31	1113	WS	
25. Yount Lee Oil Company	Chambers #19	1970		2821	5691'			S	— 5691' T.D.in salt plg. back to 5000'oldstrong
		1745	2493	1989	3794'	4/30/31	705		
26. Sun Oil Company	Wilburn Fee #14	1827	2220	1093	3954'	4/30/31	None	WS	— Stuck drill pipe,abd.
27. Humphreys Corporation/	Anne Davis #1	1454	2996	1542	5183'	4/4/1931	15	WS	
28. " " "	T. S. Fitzgerald #2	1435	2943	1537	5299'	4/23/31	1460	WS	
29a Mills Bennett Prod., Co.,	Gulf Fisher #4	1821	2903	1332	5044'	4/27/31	1720	S	
29b. Humphreys Corporation	Fitzgerald-Meadows #1	1397	2361	1464	4838'	7/25/31	1170	WS	
31. The Texas Company	J. F. Wilburn #6	1898	2368	772	4309'	8/8/31	3746	S	
32. Sun Oil Company	Anne Higgins #3	2170	2234	64	5341'	9/7/31	880	S	
33. Gulf Production Co.,	J. F. Wilburn #5	1674	2387	715	4494'	10/4/31	1700	S	
34. Mealbert Oil Company	J. F. Wilburn #4	1490	2480	990	4475'	10/4/31	2000	S	
35. Texas Gulf Producing Co.,	Sharp Fee #13	1289	2892	1603	4913'	10/10/31	1648	WS	
36. Sun Oil Company	J. F. Wilburn #1	1439	2459	980	5410'	10/23/31	800	S	Flowing by heads
37. Mills Bennett Prod., Co.,	J. F. Wilburn #8	1442	2884	1442	4407'	10/26/31	2200	S	
38. Sun Oil Company	O. H. Winfree #8	4641	4979	318	5389'	10/28/31		W	Later deepened & comp. at 5127'
39. Texas Gulf Producing Company	Kirby #2-B	1444	2238	894	4401	11/5/31	1909	S	
40. Sinclair Oil & Gas Co.	J. F. Wilburn #8	1430	2721	1291	4494'	11/7/31	1400	S	
41. Texas Gulf Producing Co.,	Warbuton #8	1617	2934	1317	4804'	11/18/31	718	S	Flowing by heads
42. The Texas Company	J. F. Wilburn #7	1517	2376	859	4402'	11/23/31	480	S	
43. Texas Gulf Producing Co.,	Barber #3-B	1361	2603	1242	4400'	12/1/31	1494	WS	
44. The Texas Company	Lawrence Fee #2	1423	2667	1245	4488'	12/2/31	90	S	Deepened to 5313 & Abd.
45. Mills Bennett Prod. Co.,	Gulf Fee #1	1368	2806	2141	5134'	12/16/31	1380	WS	
46. Gulf Production Co.,	J. F. Wilburn #6	1428	2716	1288	4471'	12/17/31	940	S	
47. Texas Gulf Producing Co.,	Morgan-Fitzgerald #1	1378	2998	2619	5234'	1/3/32	2189	WS	
48. Sun Oil Company	J. F. Wilburn /12	1490	2216	1282	4472'	1/5/32	1000	S	
49. Mills Bennett Prod., Co.,	J. F. Wilburn #6	1355	2928	1868	5034'	1/15/32	1982	S	
50. " " " "	Gulf Fisher #6	1480	2943	1463	4405'	1/15/32	2100	S	
51. Texas Gulf Producing Co.,	O. H. Fitzgerald #1	1409	3019	1910	5863'	1/19/32	2000	WS	
52. Sun Oil Company	Annie Higgins /2	1424	2649	2125	5648'	1/27/32	1400	S	
53. Sinclair Oil & Gas Co.	J. F. Wilburn #11	1423	2738	1315	4480'	2/5/32	400	S	
54. " " " "	J. F. Wilburn /10	1437	2730	1293	4849'	2/6/32	1019	S	
55. " " " "	J. F. Wilburn /9	1442	2800	1038	4880'	2/15/32	812	S	
56. Texas Gulf Producing Co.,	Kirby /2-C	1435	2606	1348	5128'	2/23/32	1300	S	
57. The Texas Company	J. F. Wilburn #8	1436	2822	1098	4407'	3/17/32	100	S	
58. Mealbert Oil Company	J. F. Wilburn #3	1403	2827	1424	4385'	3/20/32	1200	S	
59. Gulf Production Co.,	J. F. Wilburn #7	1380	2860	1480	4384'	3/24/32	900	S	
60. Sinclair Oil Company	Warbuton /8	1414	2975	1561	4407'	3/27/32		S	— Small pumper
61. Texas Gulf Producing Co.,	H. O. Scott /1	1377	3471	2094	4174'	4/19/32	1388	WS	— Orig.T.D.5429,plg.back.
62. " " "	Kirby /2-D	1374	4171	2797	4948'	4/27/32	882	WS	
63. Mills Bennett Prod., Co.,	J. F. Neese #3	1438	2852	1316	4448'	5/10/32	2200	S	
64. Gulf Production Co.,	J. F. Wilburn #8	1414	2772	1358	4382'	5/16/32	984	S	
65. Sinclair Oil Company	J. F. Wilburn #12	1386	2693	1307	4312'	5/21/32	1200	S	
66. Mealbert Oil Company	Higgins /2-C	1470	2393	923	5197'	6/3/32	288	WS	
67. Sun Oil Company	J. F. Wilburn /14	1448	2888	1440	4380'	6/17/32	1300	S	
68. Texas Gulf Producing Co.	Ilfrey /3	1410	2358	1248	4440'	6/17/32	2300	S	
69. " " "	A. S. Barber #A-9	2538	3733	1915	5880'	6/17/32	161	WS	Pumping
70. " " "	Kirby /2-10	1296	2188	1732	4376'	6/23/32	1200	S	
71. Mills Bennett Prod., Co.,	J. F. Neese #4	1407	2845	1438	4410'	7/14/32	1900	S	
72. " " "	Kirby /2	1407	2981	1574	4409'	7/21/32	2089	S	
73. Texas Gulf Producing Co.,	Cornelle Barber /3	1426	2630	1210	4300'	8/1/32	276	S	
74. Mills Bennett Prod., Co.,	A. F. Barber /A-4	2424	3282	1858	5143'	8/11/32	400	WS	
75. Texas Gulf Producing Co.,	Kirby /2-10	1394	2860	1466	5107'	8/27/32	1456	S	
76. Rio Grave Oil Company	A. E. Fisher #5	4977	5378	398	6016'	8/30/32	Dry	W	abd. 6/30/32
77. Texas Gulf Producing Co.,	Kirby /2-11	1388	2703	1315	4410'	9/11/32	1848	S	
78. Mills Bennett Prod., Co.,	Kirby /4	1370	2831	1461	4874'	9/21/32	2246	S	
79. Texas Gulf Producing Co.,	Kirby /2-4	1388	2870	1482	4878'	9/22/32	1815	S	
80. Sun Oil Company	Higgins /3	1444	2437	971	3018'	9/28/32	300	SS	
81. Texas Gulf Producing Co.,	Kirby /2-8	1394	2709	1731	5284'	9/30/32	600	S	
82. " " "	Ilfrey /4	1388	3077	1986	4834'	11/29/32	1611	S	
83. " " "	Kirby /4-11	2938	4794	1868	6130'	12/15/32	1409	WW	
84. " " "	Nolsen /2	1218	2358	1140	4784'	12/16/32	974	S	— Orig.T.D. 5315'
85. Mills Bennett Prod. Co.,	Lease /5	1383	3436	2052	4380'	12/16/32	Dry gas	S	— Later made 600 bbls PLO
86. Texas Gulf Producing Co.,	W. E. Winfree #8	3971	4463	492	5894'	12/17/32	Dry	WW	Dry End salt 6200. Abdentrozed at 6210'
87. Mills Bennett Prod., Co.,	Kirby /5	1373	3268	1795	4033'	1/3/33	477	S	
88. Texas Gulf Producing Co.,	Warbuton #9	1363	3163	1800	4060'	1/8/33	1169	S	Orig. T. D. 4680'
89. Sinclair-Prairie	Wilburn /15	1388	3143	1762	4307'	1/14/33	2000	S	
90. Mealbert Oil Company	Wilburn /8	1408	3211	1803	4328'	1/24/33	1200	S	
91. Texas Gulf Producing Co.,	Kirby /2-12	1382	3083	1631	4270'	2/27/33	1300	S	
92. Sun Oil Company	Wilburn /13	1438	3412	1180	4580'	3/9/33	381	S	Sti hole /16 in 6 hrs. 185 salt water.pumping.
				ALTO DOME, TEXAS					
1. Mills Bennett Prod., Co.,	Nanton #2	1631	1792	161					/Punked.bed oil shows
		1799	1814	15	6300'	1931	Gas	SS	\in sands below overhang.
				RICHARD DOME, TEXAS.					
1. Gulf Production Co.,	Moore #34	3077	3153	76	4389'	1932	Gas	SW	
				KEMPNER DOME, LAKE SOM TEXAS					
1. Producers Oil Company	Barrett & Greenwood #1	8162	8222	60	9195'	1917(?)	Gas	S2	
				HITCHEL DOME, LIVINGSTON TEXAS					
1. Producers Oil Company	Bruce #5	3648	3680	78	4306'	1929	Gas	S2	

FIG. 13.—Tabulation of wells drilled through overhanging salt.

Overhang.—The Pure Oil Company's Willie Bruce No. 2 was drilled through 72 feet of salt from 3,448 to 3,520 feet overlain by 92 feet of cap rock. Sedimentary formations were found beneath the salt, and at 4,007 feet the hole was in beds of the Taylor formation. The well was abandoned at 4,306 feet in shale. This is the only well on this dome where a ledge of salt has been found.

The extent of this salt ledge or overhang can not be estimated from the small amount of exploration.

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JAMIN EFFECT IN OIL PRODUCTION[1]

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ABSTRACT

The Jamin effect is defined as that resistance to liquid flow through capillaries which is due to the presence of bubbles. The actuality of this effect in the case of water is shown. It is concluded that the Jamin effect probably does not arise in the case of petroleum moving toward a producing well. That this effect retards underground water movement to any great extent appears doubtful.

One asphalt-base and one paraffine-base oil each exhibited greater adhesion for sand grains than did water under the laboratory conditions used. Hydraulic pressure produced more oil than did air pressure from similar artificial formations.

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INTRODUCTION

When the French worker Jamin was investigating the movement of sap in trees he noted, in 1860, that the presence of air bubbles can retard the flow of a liquid as it progresses through a tube of small diameter. Similarly King and Richards in this country, in their study of the capillary movement of ground water, noted that in experiments allowance must be made for this retardation. And more recently other workers have tried to estimate to what extent petroleum, travelling underground toward a producing well, is influenced by the presence of gas bubbles.

WATER AND AIR BUBBLES IN CAPILLARY TUBE

The Jamin effect, then, may be defined as that resistance to flow under pressure through a capillary tube which is encountered by liquid globules interspaced with large bubbles.[3] This effect or action is a phenomenon quite apart from frictional resistance and is due to differ-

[1] Manuscript received, September 11, 1933.

[2] Postoffice Box 1095. Introduced by T. Wayland Vaughan.

[3] M. J. Jamin, "Memoire sur l'equilibre et les mouvements de liquides dans corps poreux," *Compt. Rend. Acad. Sci.*, Vol. 50 (1860), pp. 172–76.

ential distortion of menisci in dry interspaces; the effect occurs when pressure is exerted at one end of a capillary tube containing a series of globules of water and bubbles of air, the latter of sufficient size so that the meniscus of one globule does not touch that of the next. The effect or force which resists flow under these conditions varies, among other things, with the number of bubbles and, therefore, with the number of menisci.

If a globule-bubble series such as that described in the preceding paragraph be subjected to a certain pressure, governed by the constants of the system, the menisci concave toward the higher pressure are made more concave while the oppositely directed interfaces are flattened; with this alteration of form, the lengthened menisci oppose the pressure; the result is a measurable force which resists flow.[4] That this phenomenon can and does arise is attested by Jamin's investigation and verified by those of Herold[5] and the present writer. Versluys observes, "The writer believes that the Jamin effect would not be observed in a cylindrical tube, if it were possible to work more accurately than Plateau did." The meaning of the phrase "more accurately" is not clear. Versluys then sets up the hypothetical case in which the bubbles are so small that their enclosing interfaces touch, that is, the tube is continuously wet along the length of the series.[6] This special case, inherently precluding the possibility of Jamin action, is not a criterion of the reality of that action under suitable conditions.

Considering a bubble-globule series capable of demonstrating the Jamin effect, there are two distinct cases. 1. If pressure, generated and measured by a manometer, be applied at one end of a freshly cleaned capillary, the series of globules of distilled water moves along the tube until equilibrium is reached; there is a constant pressure gradient from the higher pressure to that of the atmosphere; the menisci concave toward the higher pressure are equally distorted throughout the series. 2. If any factor, such as dirt, dissolved salts, et cetera, alters the wet-

[4] The forces involved in the vertical rise of a liquid in a capillary tube are usually written:

$$\cos \alpha = \frac{rhdg}{2T}, \text{ where}$$

$\cos \alpha$ is the cosine of the angle between the wall and the concave surface of the meniscus at their contact, r and h are the radius and height of column raised, d is the density of the liquid, g is the acceleration of gravity, and T is the surface tension of the liquid in dynes per centimeter.

[5] Stanley C. Herold, "Jamin Action—What It Is and How It Affects Production of Oil and Gas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 6 (June, 1928), pp. 659–70.

[6] J. Versluys, "Can Absence of Edge-Water Encroachment in Certain Oil Fields Be Ascribed to Capillarity?", *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 2 (February, 1931), p. 197.

ting of (adhesion of the liquid for) the tube, the behavior of the menisci is different from that already described; the menisci nearest the higher pressure are distorted more than those farther away. The more distorted interfaces are exerting more force to oppose the pressure than are the less distorted interfaces. Stated more simply, a constant pressure gradient exists along the series in case 1, while gradient is greatest nearer the higher pressure and decreases away from the higher pressure in case 2. The sizes of the bubbles are modified according to Boyle's law, as is shown by the variation of the length of the series in proportion to the pressure.

In case 2 it was observed that the pressure must be greatly augmented before the series begins to move; when motion begins it is sudden and swift; when the system comes to equilibrium the pressure may be only a fraction of that which was required to start the motion. This phenomenon suggests rigidity or solid friction;[7] once the series moves, the wall enclosing the bubbles has been wet by the preceding globules and there can be no distortion of menisci other than that due to friction. Once in motion, case 2 becomes case 1; in order that the Jamin action may again arise, the series must be moving so slowly that the tube wall containing each bubble has time to dry before the arrival of the next globule.

JAMIN EFFECT IN OIL MOVEMENT

In explanation of decreasing petroleum production from certain wells, Herold has proposed the Jamin effect. Jamin wrote in the account of his investigation of the kind of system studied here, namely, a globule-bubble series, where the globules are of oil, the series will " . . . oppose no resistance to the pressure."[8] The writer tested oil in such a system and found, like Jamin, that the resistance opposed to the pressure was *nil;* this result was predictable on the basis of the viscosity and adhesiveness of the oil for the wall of the tube which prevented the tube along the bubbles from drying. Applying pressure, the menisci were greatly distorted, yet the series moved as easily as did an unbroken column. Thus, concerning petroleum, Versluys' reasoning is correct. Unless the movement is so slow and the pores so large that the walls between the globules are dry, probably a nonexistent condition, the Jamin effect is inoperative.

It is of minor importance that, used in the sense that Versluys uses it, the term "capillarity" is a misnomer. "Capillarity" refers to

[7] George Francis McEwen, "A Mathematical Theory of the Vertical Distribution of Temperature and Salinity . . . ," *Bull. Scripps Inst. Oceanography* (La Jolla, California), *Tech. Ser.*, Vol. 2, No. 6 (1929), p. 200.

[8] M. J. Jamin, *op. cit.*, p. 175.

the force which pulls a liquid along a fine tube; the resistance to movement caused by the presence of bubbles (Jamin effect) is a secondary effect of capillarity and should not be confused with capillarity; since it is possible that capillarity itself causes some movement of both oil and water and in the interest of clarity the two effects should be differentiated.[9]

EXPERIMENTAL MOVEMENTS OF WATER AND OIL

The foregoing experiments, together with sections from works here cited, suggested the following experiments.

Cylindrical glass tubes 1.5 × 40 centimeters were filled with poorly-to-fairly rounded, chiefly quartz sand from a well sorted beach deposit the chief ingredients of which were between $\frac{1}{4}$ and 1 millimeter in diameter. Porosity of this artificial formation was 37 per cent as calculated from $\frac{\text{pore space}}{\text{volume of sand} + \text{pore space}}$.

In each case the position of the tube was horizontal.

OIL MOVEMENT UNDER HYDRAULIC AND AIR PRESSURES

Two tubes such as described were used; each was filled to 65 per cent of the available pore space with paraffine-base lubricating oil, S.A.E. rating 40. One-tenth atmosphere hydraulic pressure was applied to one tube and the same amount of air pressure was applied to the other. Under hydraulic pressure 18 per cent of the oil was delivered in the first hour. After this water began to flow increasingly, and oil decreasingly; at the end of 10 hours 75 per cent of the oil had been produced.[10] No more oil appeared.[11] The tube under air pressure gave oil more slowly; at the end of 15 hours 65 per cent of the oil had been delivered.

ABSENCE OF JAMIN ACTION IN ARTIFICIAL FORMATION

Water was forced through a fresh sand-filled tube such as is described in the foregoing paragraph; the exit end of the system was

[9] Current usage of the terms "capillary" and "capillarity" is rather loose; "capillary flow" may refer, according to the context, either to flow under pressure through fine tubes or to the additive resultant of adhesion and surface tension which causes flow. For the sake of clarity the difference should be emphasized; "capillary flow," it is suggested, might be confined to the meaning, "flow under pressure through fine tubes" (capillary means "hairlike" and connotes no force *per se*); and by "capillarity" might be meant that flow which takes place as a result of combined surface tension and adhesion.

[10] At this point water many times the volume of the tube had passed through.

[11] Norbert T. Lindtrop and V. M. Nikolaeff, "Oil and Water Content of Oil Sands, Grozny, Russia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), pp. 812–15. Under somewhat different conditions these writers get results very similar to those found here.

through a fine tube. Had the Jamin effect been operating, bubbles would have appeared in the exit tube, brought from the interstices where, moving along the capillaries between the sand grains, it might have been retarding the water flow. Under the special conditions of the experiment the Jamin effect did not arise.

ADHESIVE RELATION OF OIL AND WATER TO SAND

Oil in volume about half the system's available pore space was placed in the entrance end of one of the tubes. The sand had been thoroughly wet with water. Hydraulic pressure was applied to drive the oil through the tube; oil was distributed along $\frac{3}{4}$ of the tube's length; no oil was produced although water flowed through. The oil displaced the previously present water and stayed in the interstices despite the flushing power of the hydraulic drive. An asphalt-base oil gave the same results as the paraffine-base oil. Versluys wrote, "The minerals which constitute the strata are generally wetted more easily by water than by oil, although both liquids tends to wet a dry surface, replacing gas."[12] The question arises: if Versluys were correct, would not the water drive have expelled the oil from the spaces? Adhesive relations of water vary with dissolved materials and it is known that in flotation recovery of ores adhesive relations of oil depend on its nature. It is most likely that variations of adhesive relations of water and oil for minerals of nonmetallic luster also occur.[13] If underground conditions approximate those of the experiment, encroaching edge water flows through formations which still contain much oil.[14]

RESUMÉ

In the foregoing experiments factors other than those it was desired to observe had little or no chance to operate; further, the experiments were carried on under the special conditions of the laboratory as regards short time interval and temperature. The pressures used were low; on the other hand underground pressures are gradients.

The Jamin effect does not operate to retard flow of petroleum toward a well.

[12] J. Versluys, *op. cit.*, p. 192.

[13] "No method has as yet been discovered for the determination of the free interfacial energy between a liquid and a solid." *Internat. Critical Tables* (McGraw-Hill, New York, 1926), Vol. IV, p. 436.

[14] Chas. W. Cook, "Capillary Relationships of Oil and Water," *Econ. Geol.*, Vol. 18 (1923) pp. 167–72. Under different conditions Cook found that oil flowed through a tube of water lining a glass capillary. He notes that the factor of adhesion has been insufficiently studied in this connection.

Encroachment of edge water may be retarded by that effect under certain conditions, as where pores are large and pressure comparatively low.[15]

Oil recovery from an artificial formation was 75 per cent under hydraulic drive and 65 per cent under air pressure.

[15] F. H. King, "Capillary Movements of Ground Water," *U. S. Geol. Survey 19th Ann. Rept.*, Pt. 2 (1899), p. 85. While no retardation was noted in their work, King and Richards noted the necessity of excluding "entangled air from the sand."

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 12 (DECEMBER, 1933), PP. 1527-1533, 5 FIGS.

CLAY DIKES IN REDSTONE COAL, WEST VIRGINIA AND PENNSYLVANIA[1]

PAUL H. PRICE[2]
Morgantown, West Virginia

ABSTRACT

Clay dikes in the Redstone coal of West Virginia and Pennsylvania are so common that they are believed to result from a definite set of conditions. A similar set of conditions associated with another coal should produce clay dikes. A stratum of plastic clay closely below or above the coal is necessary. A well compacted coal, when stressed tangentially, develops a joint system with one set normal to, and another set paralleling, the direction of stress. This same well compacted coal, when stressed normal to the bedding, acts as a brittle material and forms sets of compressive shear fractures, inclined at some angle to the bedding, averaging 40°–50°. Fractures passing through the coal penetrate the under clay or an overlying clay to form a line of weakness for clay to flow through, equalizing differential pressures, thus forming clay dikes.

DEFINITION

The term clay dike is here used to designate that clastic material, mostly clay, which "cuts" or passes through the coal at some angle with the bedding. The same features have been called "clay-veins" by Gresley[3] and by Moore[4] and "clay seams" or "horsebacks" by Savage.[5] As most of these terms, "horsebacks," "clay-veins," "cut-outs," "rolls," et cetera, have been adopted from the miner's usage, they are found to occur rather loosely in the literature. Inasmuch as the features in question seem to have a definite mode of occurrence it is thought advisable to adopt the term "clay dikes" for such occurrences as here defined.

INTRODUCTION

So far as the writer has been able to determine, the Redstone coal, wherever mined, is cut by numerous dikes. Such occurrences are known in Monongalia, Barbour, and Upshur counties, West Virginia, and in Fayette County, Pennsylvania.

[1] Manuscript received, August 9, 1933.

[2] West Virginia University. Introduced by R. C. Tucker. The writer was assisted in the field study by Charles W. Furbee, Jr., and Gerald C. Bailey, major geology students.

[3] W. S. Gresley, *Bull. Geol. Soc. Amer.*, Vol. 9 (1898), pp. 35–58.

[4] E. S. Moore, *Coal* (John Wiley and Sons, 1922), p. 216.

[5] T. E. Savage, *Illinois Geol. Survey Bull. 20* (1910), p. 116.

Clay dikes are not limited to the Redstone coal, but are known to be present in the Pittsburgh and Bakerstown seams of West Virginia, and No. 5 seam of Illinois. Their presence in any seam might be expected provided conditions for their formation were favorable. The present discussion is limited to the dikes in the Redstone coal.

REDSTONE COAL

The distribution of the Redstone closely approximates that of the Monongahela series, but with considerable variation in thickness. Its stratigraphic horizon is recognized, but it is only in comparatively few localities that this seam attains a minable thickness. In general, it belongs 20–85 feet above the Pittsburgh coal, or the lower fourth of the Monongahela series. In West Virginia it varies in thickness from a thin streak to 6 feet, but only in Monongalia, Harrison, Barbour, and Upshur is it minable. In Pennsylvania its character is somewhat the same, varying in thickness from 3 to 6 feet, and is minable in Fayette, Somerset, and Westmoreland counties. In Ohio this coal retains its same general position, lying 25–35 feet above the Pittsburgh coal, but here also its thickness is variable, ranging from a mere streak to more than 4 feet. It attains a minable thickness in Meigs and Gallia counties only.

The character of the underlying and overlying material is fairly persistent, being primarily brittle, fresh-water limestones alternating with calcareous shale. In places, however, either the underlying or the overlying material may be replaced by sandstone.

OCCURRENCE OF CLAY DIKES

The field study of clay dikes for the present paper was limited to four mines: the Sesamine mine of the Gilbert Fuel Corporation and Hart's mine of the Hart Coal Company in Monongalia County and the Iris mine No. 3, of the West Virginia and Pennsylvania Coal and Coke Company, and the Kano mine No. 5, of the Peck's Run Coal Company in Upshur County. These dikes are known to be present, however, in other mines of both these fields. Of the mines here named, the Sesamine mine is by far the best locality for study.

The clay dikes vary in thickness from a fraction of an inch to several feet. The most common thickness is between 2 and 3 feet. The largest dike, 18 feet thick, is in the Sesamine mine. As can be seen from these measurements, the thickness is variable, not only among different dikes but in the same dike. In practically all places the thickness of the dike within the coal is greater than the width of the joint along which it entered. The length is also quite changeable, ranging from

a few feet to more than 100 feet. The vertical range is not definitely known, but is believed to be in general comparatively small. At no place, where more than one seam is being mined, are the dikes known to cut more than one coal. At several places where the roof had fallen away adjoining the dike for a few feet above the coal, material similar to the dike itself could be seen. In other words, at points where the exact source of the dike material could be determined it was found immediately above the roof "slates." In some places the roof at the point of emergence of the dike is quite regular, but many dikes emerge from a "roll" (horseback) or pair of "rolls" in the roof (Fig. 1).

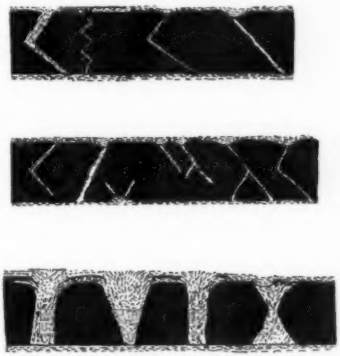

FIG. 1.—Diagrams of sketches taken from note book, of different clay dikes seen in Redstone coal.

So far as the writer has been able to determine all the dikes seen in the Redstone coal can be placed in one or the other of two classes, those that cut the coal bedding vertically and those at angles varying from 35° to 45° from the horizontal (Figs. 1–3). The latter may occupy a single plane or several planes crossing one another at different angles. In practically all places where the dikes are vertical they have the same compass direction as the butt or face joints. Some of the inclined dikes have the same bearing as either the face or butt, but their bearing is not constant (Figs. 4 and 5).

COMPOSITION OF CLAY DIKES

The clay or shale filling the fissures is ordinarily light gray and generally soft or plastic, but soon slakes or disintegrates on exposure. Where these dikes were seen in the older parts of the mine workings, small heaps of the disintegrated clay were noticed. In some places hard angular fragments of the clay were present. The clay contains

FIG. 2.—Inclined or compressional shear clay dike. Notice shearing of coal in opposite direction. Sesamine mine, Monongalia County, West Virginia.

FIG. 3.—Vertical clay dike paralleling butt joint. Sesamine mine.

fragments of coal as well as particles of the roof shale. In most places the shale is calcareous and in a few places angular fragments of limestone several inches in diameter were present.

In two samples that were analyzed petrographically gypsum was found to form a coating on the clay, with muscovite, quartz, pyrite, and chlorite common.

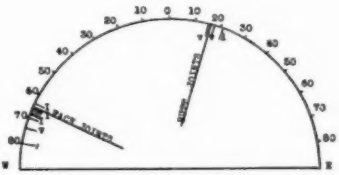

FIG. 4.—Bearings of strike of clay dikes and butt and face joints in Sesamine mine, Monongalia County, West Virginia. *v* represents vertical dikes. *I* represents inclined dikes.

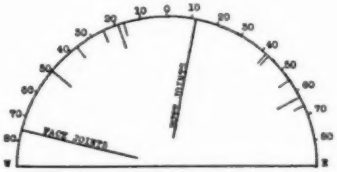

FIG. 5.—Bearings of strike of clay dikes and butt and face joints in Kano mine No. 5, Upshur County, West Virginia. All dikes are of inclined type.

ORIGIN OF CLAY DIKES IN REDSTONE COAL

In all places where the source of the clay filling the fissure could be definitely determined, it was found to come from the roof slate over the coal. Slickensides and down-drag prove the direction unmistakably. There is no reason, however, why they could not have entered from below if other conditions were favorable. The coal on either side of the clay dike is ordinarily sheared with one set of shear planes paralleling the clay dike and another set dipping in the opposite direction to form a set of conjugate shears. The angle of inclination of the shear planes is variable, but in many places it is 45°, or the theoretical angle for planes of maximum shear in perfect bodies, the variation from this depending on the amount of friction, brittleness, or ductility. The clay commonly penetrates both sets of shear fractures, but it seems most common for the clay to enter one shear as the main lead. It may follow this fracture entirely across the coal, or it may, on encountering a cross fracture, force itself in any direction along these

shears. It is for this reason that dikes which have the appearance of ending before entirely crossing the seam may, a few feet farther along its strike, attain either the top or bottom. The clay commonly penetrates the vertical butt and face joints, or it may penetrate between bedding planes in the coal. It is the latter characteristic that tends to give a very irregular appearance to the dike, although the original fracture may have been a clear-cut shear. The photographs and sketched figures illustrate all these characteristics.

As already noted, some of the well developed dikes are found standing vertical and follow either the butt or face joint. This fact and the fact that the clay penetrates the joint pattern adjacent to the coal, as well as blocks of cleated coal enclosed in the dike, prove that these dikes are post-jointing.

Savage[6] is of the opinion that the fractures are due to strains resulting from unequal shrinkage in the coal bed; that where the roof of the coal is shale, this unequal shrinkage will be relieved by rolls in the roof, but where the roof is of a hard brittle material, such as a thin limestone, fractures will occur to permit an overlying plastic shale to be squeezed downward through the fissures into the coal.

Gresley[7] has described and discussed at some length the occurrence and origin of clay veins in coal and associated strata. He offers several possible explanations for the origin of the fissures that were later filled by different types of materials, but because of the lack of an apparent structural pattern he favors earthquakes.

The conditions found in the Redstone coal are similar to those described by both Savage and Gresley. A few contrasts may be noted. It can not be assumed that, where the overlying material is a shale, all the inequalities will be relieved by the formation of rolls in the roof, as several inclined clay dikes were seen to have emerged from the base of rolls. Furthermore, the writer believes that most if not all the shrinkage in the coal was ended before the clay dikes entered the coal and that the formation of the joint system (butts and faces), as well as the inclined shears, necessitated an increase in volume. The presence of fragments of jointed coal within the clay dike shows the age of the dike to be younger than the jointing. The fact that the clay dikes are generally wider than the fissure in the roof through which they entered suggests that this contraction must have been taken up by the coal. The disturbed condition of the coal adjoining the dikes seems to bear this out. The general opinion seems to have been that the clay dikes have no general pattern, but occur haphazardly through

[6] T. E. Savage, *op. cit.*, p. 118.

[7] W. S. Gresley, *op. cit.*, pp. 50–51.

the coal. Where their direction can be plotted this seems not to be the fact, because they do have a definite bearing (Figs. 4 and 5).

It seems, therefore, that the fissures along which the clay dikes have entered are the result of a well directed stress, the direction of which operated vertically to form compressive shears. The plastic clay that lies generally a short distance above the coal has adjusted itself to differential stresses along the lines of least resistance, which are the already developed butt and face joint, and the inclined compressive shears.

The diastrophic history of the region reveals two important and several lesser post-Carboniferous adjustments: the first or Appalachian revolution which acted tangentially to fold the region and the second and later minor adjustments which acted vertically, but somewhat differentially, to uplift the area. It is probable that the clay dikes were formed during the latter movements.

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DISCUSSION

REYNOSA PROBLEM OF SOUTH TEXAS, AND ORIGIN OF CALICHE

To the editor:

Will you please print this letter in the *Bulletin* of the Association? I shall not attempt to explain the unexplainable. The first sentence in particular quoted from my letter to Dr. Price in his further discussion of the "Reynosa Problem of South Texas, and Origin of Caliche" near the top of page 1278 of the October, 1933, issue of the *Bulletin* is truly a *lapsus menti*, being totally misleading and nothing less than contrary to fact.

I feel that full justice to my highly esteemed friends, Dr. Arthur C. Trowbridge and Dr. W. Armstrong Price, demands my assuming full responsibility and at the same time my offering of my contrite apology to both. I am very glad to be able to do this because I am sure that Dr. Trowbridge's very well considered, extremely logical, complete, and coherent statement concerning the history of the Reynosa formation on pages 201 to 203 inclusive of his "Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas," Bulletin 837, U. S. Geological Survey, 1932, leaves extremely little to be desired and is by way of being about as near to the final word on the subject as it is now possible to achieve. I find myself in complete harmony with the views therein expressed. In comparison with my own hurried, incomplete, and, I fear, markedly incoherent published statements on the same subject, I am sure that everyone must decide that Dr. Trowbridge's clear exposition is greatly to be preferred. And, if my memory is not at fault, Dr. Trowbridge deserves full credit for arriving at these views independently and to him is due complete acknowledgment for their originality.

Priority is a matter over which often altogether too much pother is expended. In many cases mere accident—almost pure chance—as for instance one's being fortunate in being the first in a particular field, appears to be made the deciding factor, whereas, in reality, the credit is due to the one who first demonstrates an adequate mastery of the subject. So it is in this case, in which I willingly and gladly concede full honors to Dr. Trowbridge. I am complimented when he so clearly demonstrates a view which I, at best, have stated only in a very vague and far too incomplete way. I trust that this explanation and apology will correct, in so far as may be possible, my own most unfortunate and sincerely regretted fault which I know has resulted in an injustice to both Dr. Trowbridge and Dr. Price. Inevitably and unfortunately a certain amount of permanent injury is done in such a case as this, because always there are some who chance to read the first statement and not the later retraction of it. It is hopeless to attempt to "add an air of verisimilitude to an otherwise bald and unconvincing narrative." What I think I meant to say in my letter to Dr. Price, namely, that Dr. Trowbridge and I discovered we had common ideas not hopelessly at variance, is very obviously not what I really did say.

Very truly yours,
CHARLES LAURENCE BAKER

BUREAU OF ECONOMIC GEOLOGY,
THE UNIVERSITY OF TEXAS,
AUSTIN, TEXAS
October 23, 1933

COASTAL PLAIN STRATIGRAPHIC NOMENCLATURE

Mr. John M. Vetter
President, Houston Geological Society
Dear Sir:

This committee, which was appointed to attempt the unification of stratigraphic nomenclature for economic reports, first met on July 8. We agreed that the best possible starting point was on those beds lying beneath the "rice" sands and above the Wilcox. Upon comparing notes, we found that for these beds we were using with few exceptions the same criteria for correlation. In every case we were using the first appearance or top range of various marine fossils.

For instance we were all noting the first appearance of shell fragments and (or) Ammobaculites below the "rice" sands; thus we all have a common point within the limitations imposed on us by variances in the cuttings distributed. These beds have been referred to by different men variously as Frio, Vicksburg, and Fayette. Thus, while we are all in agreement as to the position of this point in the column, we are in disagreement as to its outcrop equivalent. Again we find that, based on the upper range of *Ceratobulimina eximia*, which we all recognize, the following names are applied to the beds lying below the top of its range and the top of either *Textularia "smithvillensis"* or *Lamarckina claibornensis:* Cook Mountain, Lower Saline Bayou, or Crockett. Here again we have confusion resulting from an attempt to refer our subsurface beds to the outcrop. This confusion results in part from the lack of monographic treatment of the microfossils occurring on the outcrop, and also to the presence of non-marine wedges on the outcrop, the position of which is occupied by marine beds down-dip.

It seems agreed that a formation is a lithologic unit. All who have examined the outcrop and studied well sections will agree that there is a loss of lithologic peculiarity down dip. It is our experience in this province that down dip the sands tend to disappear and must grade laterally into argillaceous sediments which are not to be distinguished on a lithologic basis from those clays lying above and below. Thus while the Jackson and Claiborne may readily be broken into lithologic units on the outcrop, down dip they form rather a monotonous brown mudstone sequence with fewer and fewer sand intercalations away from the outcrop. Supposedly, our standard geological column is based on the marine sequence. Naturally, when only non-marine beds were available to the geologists, as was often the case before well data were available to us, these non-marine beds were of necessity used in establishing the geologic column. However, we now have data available to us from the wells in which the column is much more largely marine than the outcrop to which attempts have been made to refer the well samples. It is, therefore, recommended that for subsurface purposes we erect a zonation based on the upper ranges of various marine fossils (in practice mostly *Foraminifera*) and attempt to fit the outcrop into this more largely marine section rather than vice-versa. It is true that no perfection may be expected in this, but on the other hand we may rid ourselves of the chaotic nomenclature which has been bothering those of our members who receive reports from various paleontological laboratories.

So the committee recommends, in the zonation of these beds below the

base of the "rice" sands and above the Wilcox, that the following fossils be noted in the order of their appearance:

(1) First shell fragments or Ammobaculites
(2) " *Textularia warreni*
(3) " *Marginulina cocoaensis, Uvigerina, Valvulineria texana*
(4) " *Massilina pratti*
(5) " *Textularia hockleyensis*
(6) " *Textularia dibollensis*
(7) " *Nonionella* sp.[1]
(8) " *Eponides yeguaensis*
(9) " *Ceratobulimina eximia*
(10) " *Textularia* sp.[1]
(11) " *Lamarckina claibornensis*

Any other zonal markers may be interpolated as desired. The committee has no objection to the inclusion of the so-called formational name following the zone fossils if desired; for example: *Ceratobulimina eximia* (Crockett).

Also some confusion exists, due to the fact that very often samples are assigned to a zone, or a so-called formation, not on the basis of the zone fossil itself but either on the basis of fossils making their appearance at approximately equivalent points or on the basis of lithology. In these cases it is recommended that procedures somewhat like the following be used: *Textularia dibollensis* (association), or first *Textularia dibollensis* (lithology). Should the zone fossil itself make its appearance below the appearance of its equivalent fauna, or supposedly equivalent lithology, it should be listed as found. It is felt that this procedure should take place, as the paleontological report should be nothing more than a report of the facts found from a study of the samples available. *It should not be an interpretation.* If an interpretation is desired by the operator or the company employing the paleontologist, the interpretation should be so labeled. It is felt that interpretations are legitimate but that they should not be confused with a paleontological report, which, we repeat, should be confined to the facts.

We believe that if this procedure is followed, the reports from various laboratories will agree in so far as the samples available to the various laboratories give similar evidence and the variance in personal concept of a species (which can not be entirely eradicated) will permit.

This system of terminology is recommended for that strip of the Coastal Plain in which conditions exist similar to those at Conroe, Tomball, Raccoon Bend, Pettus, and Tuleta.

M. C. ISRAELSKY, *chairman*
RALPH C. BREHM JOHN C. MILLER
MARCUS A. HANNA F. W. ROLSHAUSEN

HOUSTON, TEXAS
August 19, 1933

GEOLOGY OF BLUE SPRINGS GAS FIELD JACKSON COUNTY, MISSOURI

I should like to say a few words regarding the review of my paper "The Geology of the Blue Springs Gas Field, Jackson County, Missouri" by Mr. Eugene A. Stephenson in the September issue of the *Bulletin*, pp. 1148–53.

[1] Known respectively by nude names *Nonionella cockfieldensis* and *Textularia smithvillensis*. It is expected they will be described shortly.

With twenty-three uncomplimentary references to the report skillfully included in the four-page review, it must be apparent to the most casual reader that Professor Stephenson does not approve of the article.

An analysis of his criticism makes it clear, however, that it is chiefly the behavior of the gas wells, rather than the nature of the report, to which he objects. I am in the position of the meteorologist who is being blamed for an inconvenient thundershower, of a census enumerator who unfortunately finds deplorably crowded conditions.

While purporting to be a review of the article as a whole, the first two-thirds of the paper is ignored except for one gratuitous remark in which he denies that the synclines are the dominant structural features. This is entirely a matter of opinion and need not be discussed further.

His chief point of criticism is regarding the actual production statistics. In considering the rock-pressure decline he feels that I am

> obviously unacquainted with methods for calculating weighted averages, or in the case of gas fields, with the necessity of taking into consideration the areal distribution of the various pressures.

In this particular case the methods of operation have taken care of this problem nicely. On page 35 I state,

> The Blue Springs field has been divided into districts based upon the date of connection of the wells to the main line system.

Again on page 39 the statement is made

> in each district all wells were hooked into the main line system at about the same time. The production record is the same, therefore, as if all the wells in each district had been drilled at the same time.

The rock pressure was the same in each district, the wells were in the middle of forty-acre tracts, with few exceptions, and all of the wells were produced as a unit. In the history of the field the differences in rock pressure between wells were trifling and, strange as it may seem to the reviewer, the "mathematical average of well pressures" must have been very, very close to the "true average pressure of the gas field."

It is quite true that the cumulative production curve (which I discussed on page 40) is smoother and perhaps more pleasing to the mathematical engineer, but the stubborn fact remains that the yield of gas per pound—supposedly constant under Boyle's law—varies from 8 million to 77 million cubic feet in the West district, and from 10 million to 124 million cubic feet in the East district. It is of little comfort to say with the reviewer, ". . . if the drop in pressure" [in a certain instance] "had been 6 pounds" [instead of 3.1 pounds] "the yield . . . would have been. . . ." The fact is that the drop in pressure was only half the suggested hypothetical figure.

It is charged that I misquoted Johnson and Morgan, and that I misinterpreted Versluys. I deny the misquotation, and I have a very friendly letter from Dr. Versluys in which, after reading my paper, he fails entirely to chide me for misunderstanding him.

In conclusion, I want to thank Professor Stephenson for citing the five references, which, it happens, I had already read, and to express regret that he, the reviewer, has not seen fit to publish, so far as I have been able to ascertain, any contribution to this very interesting and important field of investigation.

GLENN G. BARTLE

KANSAS CITY, MISSOURI
October 25, 1933

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 12 (DECEMBER, 1933), PP. 1538-1542

REVIEWS AND NEW PUBLICATIONS

"Boulders of Bengalia." By WILLIAM B. KRAMER. *Jour. Geol.* (University of Chicago Press), Vol. 41, No. 6 (August–September, 1933), pp. 590–621.

This paper deals with the erratic boulders in the Johns Valley shale of the Ouachita Mountains of Oklahoma, and offers a new hypothesis for their origin from conclusions based on examination of the literature and with minor supplemental field observations.

Briefly, Mr. Kramer contends that the boulders have been removed by submarine landslides into the Johns Valley sea from islands made up of pre-Pennsylvanian rocks of Arbuckle facies, which had been originally deposited in close association with pre-Pennsylvanian rocks of Ouachita facies. Later, he believes that the area was uplifted differentially by normal faulting, and that subsequent erosion has exposed the hypothetical islands of pre-Pennsylvanian rocks at Stringtown, Potato Hills, and many other localities.

This novel hypothesis undoubtedly would answer many of the perplexing questions of the Ouachita area, were it not based on premises which are untenable. The most important assumption is that rocks of Arbuckle and Ouachita facies have been deposited co-extensively, either by interdigitation or interbedding. This assumption would permit the boulders of Arbuckle facies at Bengal to be removed by landslides from the Potato Hills, an "island" of rocks of Ouachita facies. Definite and adequate variations in faunal and lithologic characteristics of the two facies, as pointed out by Ulrich, show conclusively that the two facies were deposited in well separated localities and the Bengal boulders could not possibly be derived from the Potato Hills area of "Bengalia."

Inasmuch as the two facies were deposited at widely separated areas, the Arbuckle facies must have been deposited in closer proximity to the Arbuckle Mountains than the Ouachita facies. That puts the normal position of the rocks of Arbuckle facies northwest of the other series. Thus the rocks of Arbuckle facies in the Hansen *et al.* well in the SE. ¼, NW. ¼, of Sec. 17, T. 4 S., R. 11 E., are in their normal location west of the disturbed area of the Ouachita Mountains, while the rocks of Ouachita facies at Stringtown are clearly displaced laterally from their area of deposition farther southeast.

At Wesley and Ti Valley are definite exposures of the Arbuckle sequence which have been displaced by buckling and thrusting and have been closely approached by rocks of the Ouachita sequence thrust further northward from their original location.

The author questions the presence of thrust faults involving great distance of overthrusting, which would be necessary to bring about such lateral displacement. He believes that the apparent high inclination of the fault planes at the surface argues against the presence of such faults. I refer to Quirke's[1] experiments which show how steeply dipping thrust faults may flat-

[1] T. Quirke, "Concerning the Process of Thrust Faulting," *Jour. Geol.*, Vol. 28 (1928), pp. 417–38.

ten at depth. The author recognizes that the planes of such faults may be folded, but prefers to explain observed field relations by normal faulting, rather than thrust faulting. Since the rocks of the region have been compressed by folding alone, so that they now occupy a belt about half the width of the original extent, it seems obligatory to assume that there are thrust faults of great magnitude in the region.

All the faulting in the Ouachita region took place in late Pennsylvanian time. The faults in the Mexia and Powell zone, which the author thinks to be related to those in the Ouachita region, are as stated by him normal faults. They were produced by movements in the Coastal Plain region in Tertiary time. Where the Choctaw fault disappears under the Cretaceous rocks there is no displacement of them. This proves that the Choctaw fault was quiescent since pre-Cretaceous time. The Balcones and Mexia fault zones indicate a slight stretching of the earth crust, while the thrust faults of the Ouachita region indicate considerable shortening of the earth crust. Furthermore, the Balcones fault zone is now known to turn east and pass south of the Ouachita uplift. The difference in time of movement, the difference in mechanical origin, and the lack of connection of the two fault zones argue against the relation suggested by the author. The only relation that these faults may bear to structural trends in the Ouachita geosyncline appears to be, that they represent a movement along lines of structural weakness.

The author stands alone in his ascribing a non-exotic origin to the boulders. All other geologists, including Taff, Ulrich, Powers, Miser, Stille, van der Gracht, Honess, Tomlinson, and myself, hold the opinion that the boulders came from a facies of rocks dissimilar to the Ouachita sequence. The author's hypothesis of a non-exotic origin for the boulders is based in part on his assumption—not supported by evidence—that areas of Arbuckle rocks were deposited in portions of the Ouachita region and that high projecting islands shed boulders by landslides in the adjoining sea. Also his hypothesis is based in part on his erroneous assumption that the rocks lying between the Ti Valley and Choctaw faults belong to the Ouachita facies, while as a matter of fact, as previously stated, they do belong to the Arbuckle facies.

The fundamental question as to the origin of the boulders, whether they result from glaciation, overthrusting, mudflows or submarine landslides, remains yet to be solved. A satisfactory solution may never be attained, not only because of the difficulties of some of the structural relations in the mountains, but also because the areas from which the boulders are derived are entirely concealed. Submarine landslides, as postulated by the author, may be a plausible explanation of the movement of the boulders from the parent ledges into the area of Johns Valley deposition. This is one of the several hypotheses that have been advanced by geologists familiar with the area to explain the origin of the boulders.

Many features of the paper deserve detail comment and discussion, but space does not here permit this to be done.

BRUCE H. HARLTON

TULSA, OKLAHOMA
November 4, 1933

An Introduction to the Study of Fossils. By H. W. SHIMER. Revised edition. The MacMillan Company (New York, 1933). 496 pp., 207 figs., time scale, 2 tables. 5.5×8 inches. Price, $4.00.

Because of its orderly and systematic arrangement, the balanced and adequate treatment of each phylum, and the wealth of apt illustrations, the reviewer has considered the book before its recent revision the best one available for beginning students, and he has used it as a text-book in the beginning courses for many years.

The revision has increased the material of the text by about one-ninth, and the number of figures by one-sixth, yet with a good grade of thinner paper the revised edition is only two-thirds as thick as the older one. Thus it is in a more compact and handy form. The introductory chapter of the old edition is expanded in the new edition and the figures increased. It gives the student a good idea of what fossils are, how fossilization takes place, the relation of the fossil to the living form, and the materials of which fossils may be composed. The geologic time scale and the tables of plant and animal kingdoms follow the first chapter instead of being at the end of the book as in the former edition.

Instead of a single chapter on plants the new edition has four separate chapters, one for each of the four great groups of plants, with much new descriptive material added, and the plants which are important in rock formation are emphasized and their importance as rock-builders is stressed.

In the treatment of the animal group, one major change has been made in classification. Though treated in the chapter on Coelenterata, Ctenophora has been raised from a class under that group to the rank of a separate phylum, thus increasing the number of phyla from twelve to thirteen. Except for the four phyla of the Vermes, Platyhelminthes, Nemathelminthes, Trochelminthes, and Annelida, which are treated together in a single chapter, each of the other phyla, Protozoa, Porifera, Echinodermata, Molluscoidea, Mollusca, Arthropoda, and Chordata is treated in a separate chapter. Near the end of each chapter the evolution of the group is considered and their importance as rock-builders noted in all those forms which have contributed to the formation of rocks.

Each phylum is generally divided into classes, subclasses, and some into orders, with some of the more important genera and species illustrated, and their parts and structure described in detail. A set of comprehensive review questions follows the discussion of each of the important groups, also, the derivation and meaning of the group names are given.

Thus in the revision, the addition of some new descriptive material with many new illustrations, the consideration of the evolution of each of the larger groups, and the estimation of the importance of each group as a rock-builder have added materially to the value of the already very satisfactory textbook.

CHARLES E. DECKER

UNIVERSITY OF OKLAHOMA
NORMAN, OKLAHOMA
October 27, 1933

RECENT PUBLICATIONS

ALABAMA

State of Alabama. U. S. Geol. Survey base map, as revised in 1925, printed in black. Shows county boundaries, towns, railroads, rivers. No contours. Scale, 1 inch = 16 miles. Director, U. S. Geol. Survey, Washington, D. C. Price, $0.50.

GENERAL

"Der Verbleib der organischen Substanz der Tiere bei meerischen Einbettung" (What Remains of Organic Substance of Animals in Marine Sedimentation), by Franz Hecht. *Senckenbergiana* (Frankfurt a. M.), Vol. 15, No. 3–4 (June 29, 1933), pp. 165–249; 19 figs.

"Le facies des séries pétrolifères et leur paléogéographie en Europe et dans le proche orient" (The Facies of the Petroliferous Series and their Paleogeography in Europe and in the Near East), by Jean Jung. *Annales des Combustibles Liquides* (Paris, July–August, 1933), pp. 631–44; 1 map.

"Origin of the Anhydrite Cap Rock of American Salt Domes," by M. I. Goldman. *U. S. Geol. Survey Prof. Paper 175-D* (July, 1933), pp. i–iii, 83–114, pls. 24–42. Supt. of Documents, Govt. Printing Office, Washington, D. C. Price, $0.15.

GEOPHYSICS

"Analysis of Seismic Profiles," by Irwin Roman. *Amer. Inst. Min. Met. Eng. Contrib. 64*, Class L, Geophys. Prosp. (November, 1933), 35 pp., 5 figs.

"Über die seismische Reflexionsmethode" (The Seismic Reflection Method), by C. A. Heiland. Reprint from *Ergänzungs-Hefte für angewandte Geophysik* (Akad. Verlagsgesellschaft m.b.H., Leipzig), Bd. 3, Heft 3 (1933), pp. 282–336; 9 figs; abstract in English.

"Elements of Geophysical Prospecting, as Demonstrated at A Century of Progress, Chicago, 1933, in the Geophysics Section of the American Petroleum Industries Exhibit," by C. A. Heiland. *Quart. Colorado School Mines* (Golden), Vol. 28, No. 4 (October, 1933), pp. 1–52; 20 figs.

GERMANY

"Auswalzungsgrade in Gefolge 'Disharmonischer Faltung' im Zechsteinsalzgebirge des mittleren Leinetales" (Disharmonic Folding in the Zechstein Salt Formations of the Middle Lein Valley), by G. Hartwig. *Kali, Verwandte Salze und Erdöl* (Wilhelm Knapp, Halle, Saale), Vol. 27, Nos. 17–20 (September 1–October 15, 1933), 18 pp., 20 figs., unfinished. Describes complicated minor folding.

MICHIGAN

State of Michigan. U. S. Geol. Survey base map, newly completed. Culture in black; water in blue. No contours. Scale, 1 inch = 8 miles. Director, U. S. Geol. Survey, Washington, D. C. Price, $0.50.

"Oil and Gas Fields of Michigan," by Robert B. Newcombe. *Michigan Dept. Conserv. Geol. Survey Div. Pub. 38*, Geol. Ser. 32 (Lansing, 1933), vii + 293 pp., 10 pls., 41 figs., 23 tables. Price: cloth, $2.50; paper, $2.00.

PETROGRAPHY

"Beitrag zur Sedimentpetrographie des Miocän der Gasbohrung von Neuengamme bei Hamburg, nebt einer Erklärung der gesetzmassigen Schwermineralverteilung" (Sedimentary Petrography of the Miocene in the Gas Wells of Neuengamme near Hamburg, with an Explanation of the Regular Distribution of Heavy Minerals), by Wilhelm Georg Simon. *Centralb. f. Min.*, etc., Pt. B., No. 5 (1933), pp. 257–63; 1 fig., 2 tables.

"Verwendung einer neuen sedimentpetrographischen Methode auf die

Miozänstratigraphie und Tektonik im Erdgasgebiet von Neuengamme" (Application of a New Sedimentary Petrography Method to the Miocene Stratigraphy and Tectonics in the Natural Gas Region of Neuengamme), by W. G. Simon. *Neues Jahrbuch f. Min.*, etc., Beil. Bd. 70, Abt. B (1933), pp. 139–57; 2 pls., 10 tables.

"Anwendung einer neuen sedimentpetrographischen Methode auf die Miozänstratigraphie und Tektonik im Erdgasgebiet von Neuengamme" (Use of a New Sedimentary Petrography Method in the Miocene Stratigraphy and Tectonics in the Natural Gas Region of Neuengamme), by W. G. Simon. *Kali, Verwandte Salze und Erdöl*, Vols. 13–14 (1933), 7 pp., 7 figs.

"Die Bedeutung der Sedimentpetrographie für die Erdölgeologie in Deutschland" (The Significance of Sedimentary Petrography in Petroleum Geology in Germany), by W. G. Simon. *Internat. Zeits. f. Bohrt., Erdölb., und Geol.* (Vienna), Nos. 15–16 (1933), 7 pp., 3 figs.

ROUMANIA

"Uebersicht über den Charakter der Erdöllagerstätten Rumäniens" (Review of the Character of Petroleum Formations of Roumania), by L. Mrazec. German translation by R. Noth. *Internat. Zeit. f. Bohrt., Erdölb. und Geol.* (Vienna), Vol. 41, No. 20 (October 15, 1933), pp. 227–32, 2 figs. First installment. From original, "Aperçu sur le caractère des gisements de pétrole de la Roumanie," *Spisy Prirodovedecka Fakulta Karlovy Univ. Prag.*, 55 pp., 1 map, 15 profiles.

TENNESSEE

The Tennessee River Basin. U. S. Geol. Survey map in 5 colors. Scale, 1 inch = 8 miles. Shows character and distribution of mineral resources, including oil and gas, in the greater part of Tennessee and Kentucky, and adjacent parts of Virginia, West Virginia, North and South Carolina, Georgia, Alabama, Mississippi, and Missouri. For sale by U. S. Geological Survey, Washington, D. C. Price, $1.00. 40×64 inches.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 12 (DECEMBER, 1933), PP. 1543-1546

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive commiteee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Pascual Sgrosso, Buenos Aires, Argentina, S. A.
John O. Bower, George A. Severson, Frank B. Notestein

FOR ASSOCIATE MEMBERSHIP

William Bernard Sinclair, Wichita, Kan.
E. A. Wyman, Dollie Radler Hall, Jess Vernon

FOR TRANSFER TO ACTIVE MEMBERSHIP

Elba L. Fipps, Joplin, Mo.
H. E. Minor, P. B. Leavenworth, Marcus A. Hanna

SAN ANTONIO SECTION FIFTH ANNUAL MEETING

The fifth annual meeting of the San Antonio Section of the Association at the Plaza Hotel, Corpus Christi, Texas, October 28, was attended by approximately 200 geologists. A feature of the meeting was the opening address of Robert T. Hill. The technical program included the following papers.

1. "Surface Geology of the Jackson, Catahoula, and Lower Oakville from Grimes County to Gonzales County, Texas," by B. Coleman Renick.
2. "The McFaddin-O'Conner, Greta, Fox, Refugio, White Point, and Saxet Fields," by A. E. Getzendaner.
3. "A Comparison of the Structural and Sand Conditions of the Conroe, Tomball, and Pettus Oil Fields, Texas," by L. P. Teas.
4. "Present Efforts in Geophysical Surveying," by Paul Weaver.
5. "Tectonic History of the Balcones System," by Charles Laurence Baker.
6. "A Preliminary Interpretation of the Late Tertiary and Quaternary History of South Texas," by Ed. W. Owen.
7. "The Mount Selman Formation of Frio County, Texas," by L. W. Clark and L. W. MacNaughton.
8. "Stratigraphy of Starr County and Southern Zapata County, Texas," by Earle R. Wall.

During the afternoon, the ladies were entertained at the Corpus Christi Country Club. At night, there was a dinner dance on the Plaza Hotel Deck.

A pre-convention field trip on October 27, across the Lissie and Beaumont formations from Victoria to Corpus Christi, was conducted by Sam Grinsfelder, chairman; Gage Lund, Rual Swiger, C. C. Miller, A. E. Getzendaner,

W. A. Maley, Ike Howeth, and H. N. Seevers. Following the convention, on October 29, a trip on the outcrop of the Goliad and Lagarto formations from Casa Blanca to George West, Texas, was conducted by H. T. Richardson and Lon D. Cartwright, Jr.

The officers of the San Antonio Section are: president, L. F. McCollum; vice-president, Fred P. Shayes; secretary-treasurer, Julian Q. Myers; executive committee members, Ed. W. Owen and Dilworth S. Hager.

The program committee was: T. J. Galbraith, chairman; Charles H. Row, Fred P. Shayes, Joseph M. Dawson, E. L. Porch, A. W. Weeks, W. A. Maley, Don Danvers, Rual Swiger.

The arrangements committee was: W. Armstrong Price, chairman; Adolph Dovre.

The masters of ceremony at the dinner dance were: H. N. Seevers, chairman; Mrs. R. E. Rettger; Jack Hagan.

The ladies entertainment committee was: Mrs. W. A. Maley, chairman; Mrs. H. N. Seevers; Mrs. A. E. Getzendaner.

PACIFIC SECTION TENTH ANNUAL MEETING

The tenth annual meeting of the Pacific Section was held at Los Angeles, November 9–10. Attendance at the general meeting was about 200; at the business meeting about 70. Frank R. Clark, of Tulsa, Oklahoma, president of the Association, was present. Special entertainment was a dinner dance at the Paris Inn. Technical sessions at the Southern California Edison Company Building and at the Clark Hotel included the following papers.

1. "Preliminary Geological Map of the Las Flores and Dry Canyon Quadrangles, Western Santa Monica Mountains, California," by E. K. Soper and U. S. Grant.
2. "Origin and Accumulation of Oil," by Frank R. Clark.
3. "The Possibilities for Oil and Gas Fields on the Northwest Flank of the San Joaquin Valley from Coalinga to Livermore Pass," by Clarence B. Osborne and Lee S. Osborne.
4. "An Application of Professor Stille's Structural Methods," by R. D. Reed.
5. "The Structure of the Balearic Islands," by J. S. Hollister.
6. "An Interpretation of the Structure of the Huntington Beach Oil Field and Its Significance," by Hoyt S. Gale.
7. "The Stratigraphy of the Temblor in the Coalinga District," by John Galloway.
8. "Geology of a Portion of the Salinas Valley," by James M. Douglas.
9. "Experiments Testing Seismographic Methods for Determining Crustal Structure," by John P. Buwalda, H. Benioff, and B. Gutenberg.

Dues in the Section were reduced from $2.00 to $1.00 per year. The newly elected president of the Section is A. A. Curtice, succeeding Frank A. Morgan. Wilbur D. Rankin was re-elected secretary-treasurer.

The Pacific Section of the Society of Economic Paleontologists and Mineralogists presented a program under the chairmanship of Paul B. Goudkoff as follows.

1. "Structure and Stratigraphy of the Eocene North of Simi Valley," by T. F. Stipp and F. B. Tolman.
2. "A Study of a Pliocene Section at Canada de Aliso, Ventura County, California," by Bradford C. Adams.
3. "Progress Report of the Committee on Miocene Nomenclature," by A. J. Tieje.

RESEARCH COMMITTEE

A dinner and round table discussion are being planned by the research committee for Wednesday evening before the official opening on Thursday of the annual meeting of the Association at Dallas, Texas, next March.

The primary topic on which the discussion will be started is: "Time of Migration of Petroleum, with Especial Reference to the Age of Petroliferous Structures and to Levorsen's 'Studies in Paleogeology'" (September *Bulletin*).

This dinner is a "get-together" primarily for members of the Association who are much interested in research; and the round table is primarily for those who can contribute pertinently to the discussion, but other members of the Association will be welcome.

DONALD C. BARTON *chairman*

HOUSTON, TEXAS
November 10, 1933

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

FRANK R. CLARK, *chairman*, Mid-Kansas Oil and Gas Company, Tulsa, Oklahoma
WILLIAM B. HEROY, *secretary*, Sinclair Exploration Company, New York, N. Y.
FREDERIC H. LAHEE, Sun Oil Company, Dallas, Texas
GEORGE SAWTELLE, Kirby Petroleum Company, Houston, Texas
L. C. SNIDER, H. L. Doherty and Company, New York, N. Y.

GENERAL BUSINESS COMMITTEE

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RESEARCH COMMITTEE

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H. A. LEY (1934)
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REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

R. S. KNAPPEN (1934)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

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IRA H. CRAM
ALEXANDER DEUSSEN
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A. I. LEVORSEN
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FINANCE COMMITTEE

E. DEGOLYER (1934)
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JOSEPH E. POGUE (1936)

COMMITTEE ON APPLICATIONS OF GEOLOGY

F. H. LAHEE, *chairman*, Box 2880, Dallas, Texas

WILLIAM H. ATKINSON
DONALD C. BARTON
FORD BRADISH
ARTHUR E. BRAINERD
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W. F. CHISHOLM
HERSCHEL H. COOPER
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R. B. WHITEHEAD

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

W. B. HEROY, of the Sinclair Exploration Company, New York City, was in the Gulf Coast region, with temporary headquarters at Houston, in November.

President FRANK R. CLARK visited the geological societies at Shreveport, Louisiana, and Houston, San Antonio, San Angelo, and Fort Worth, Texas, last October. He also attended the annual meeting of the American Petroleum Institute at Chicago, October 23–26. In November he went to the West Coast, attending the annual meeting of the Pacific Section of the Association at Los Angeles, November 9 and 10, and visited Association members in San Francisco, California, Salt Lake City, Utah, and Denver, Colorado.

FREDERIC H. LAHEE, while at the American Petroleum Institute convention at Chicago, talked, October 23, on "The Present Status of Petroleum Geology," before the students and faculty members of Kappa Epsilon Pi, the geological fraternity of the University of Chicago.

The 46th meeting of the Geological Society of America will be held at Chicago, December 28, 29, and 30, 1933, under the auspices of the University of Chicago, Northwestern University, and the Chicago Geological Society. The Reynolds Club at the University of Chicago is headquarters.

The Society of Economic Geologists holds its annual meeting in conjunction with the meeting of the Geological Society of America, at Chicago, December 28, 29, and 30, 1933.

At the regular meeting of the Tulsa Geological Society, November 6, HARRY F. WRIGHT spoke on "Bottom-Hole Pressures."

VAN COURT WARREN, consulting geologist and mining engineer, announces the removal of his office and residence from Los Angeles to Auburn, Placer County, California, to carry on his practice in consulting geology, mining engineering, and management.

The Houston Geological Society elected the following officers at their annual meeting October 6: president, MARCUS A. HANNA, Gulf Production Company; vice-president, W. F. BOWMAN, Tide-Water Oil Company; secretary-treasurer (re-elected), JOHN C. MILLER, The Texas Company.

The Mid-Continent section of the American Institute of Mining and Metallurgical Engineers and the Tulsa Geological Society held a joint meeting at the University Club Auditorium, Fifth and Cheyenne Streets, Tulsa, Oklahoma, October 23, at 8:00 P.M. J. A. CUMMIN, of Dowell, Inc., spoke on some "Ins and Outs of Acid Treatments."

HUGH D. MISER, United States Geological Survey, Washington, D.C., spoke before the Tulsa Geological Society, Monday, October 15, at 8:00 P.M., on "Some Problems of the Ouachita Mountains."

NORMAN E. WEISBORD has changed his address from Apartado 10, Matanzas, Cuba, to 227 Haven Avenue, New York, N.Y.

R. P. LOCKWOOD, formerly of Lamar, Missouri, has accepted a position in the geological department of the Gypsy Oil Company, with headquarters at Guthrie, Oklahoma.

HENRY F. SCHWEER resigned his position with the Danciger Refineries at Longview, Texas, to go with the Portland Cement Association, September 1, 1933. Schweer's headquarters is at 1421 First National Bank Building, Oklahoma City.

MARTIN W. BADEN, who has for the past ten years been connected with the Benedum-Trees Oil Company, of Pittsburgh, Pennsylvania, and The Trees Oil Company of Winfield, Kansas, has resigned and will continue his consulting practice at 201 Baden Building, Winfield, Kansas.

ROBERT H. DOTT, consulting geologist, Tulsa, presented a paper before the Oklahoma City Geological Society, October 9, on "Contributions to the Arbuckle Mountain Structures."

JOHN R. ROBERTS died at Los Angeles, California, on October 7.

A. F. MELCHER, consulting geologist and physicist, formerly with the Marland Oil Company, the United States Geological Survey, and the United States Bureau of Standards, died on October 22 at Tulsa, Oklahoma.

LOUIS C. ROBERTS, JR., of the Stanolind Oil and Gas Company, has moved from Fort Worth to Houston, Texas, where his address is 2912 Gulf Building.

W. J. NOLTE, of the Stanolind Oil and Gas Company, has succeeded LOUIS C. ROBERTS, JR., as secretary-treasurer of the Fort Worth Geological Society.

WILLIAM F. LOWE, *National Petroleum News* staff writer, has changed his address from 1607 East Twelfth Street, Tulsa, to 12505 Edgewater Drive, Apartment 406, Cleveland, Ohio.

At the annual election of officers of the North Texas Geological Society held October 12, 1933, the following men were named for the coming year: president, RALPH S. POWELL, chief geologist for The Texas Company, Wichita Falls; vice-president, J. R. SEITZ, 532 Waggoner Building, Wichita Falls; secretary-treasurer, TOM L. COLEMAN, district engineer for the United States Geological Survey, 302 Federal Building, Wichita Falls, Texas.

R. VON ZWERGER, formerly geophysicist with the Ohio Oil Company, Shreveport, Louisiana, opened an office as consulting geophysicist at Berlin, Germany. From 1931 to 1932 he was associated with the Wintershall Aktiengesellschaft, Kassel, Germany, as consulting geophysicist. His address is Berlin-Zehlendorf, Teltowerstr. 17.

SAMUEL WASHINGTON MCCALLIE, state geologist of Georgia since 1908, died October 26, at the age of 77 years.

HENRY C. CORTES, geologist with the Magnolia Petroleum Company, has changed his address from Lake Charles, Louisiana, to Houston, Texas.

HENRY C. LAY has resigned from the Venezuela Gulf Oil Company, at Ciudad Bolivar, Venezuela, and has accepted a position as exploitation engineer with the Shell Petroleum Corporation. He is stationed at Iowa, Louisiana.

J. A. MCCUTCHIN, exploitation engineer for the Shell Petroleum Corporation, has been transferred from Earlsboro, Oklahoma, to McPherson, Kansas.

W. MELVIN STIRTZ has changed his address from Drawer L, Bartlesville, Oklahoma, to 4920 La Branch, Houston, Texas.

D. H. RADCLIFFE, geologist, Los Angeles, California, sailed November 3, for a six months' trip around the world.

M. G. EDWARDS, geologist, Shell Oil Company, Los Angeles, California, has returned from a six months' business trip to The Hague, Holland, and the Roumanian oil fields.

WALTER S. OLSON, formerly of San Diego, California, has been employed by the Colombian Petroleum Company, as field geologist in the Barco concession. His address is Apartado 100, Cucuta, Colombia, S. A.

HOMER A. NOBLE, formerly consulting geologist at Houston, Texas, is now employed in the San Antonio office of the Magnolia Petroleum Company.

LEE C. SMITH has resigned as geologist for the Conservative Oil Company, with headquarters at San Antonio, to accept a position as paleontologist in the laboratory of the Sun Oil Company, with headquarters at Dallas, Texas.

ARNOLD S. BUNTE, formerly assistant exploitation engineer for the Shell Petroleum Corporation, at McPherson, Kansas, is now district exploitation engineer for the same company at Greenwich, Kansas.

The department of geophysics at the Colorado School of Mines, Golden, is offering for the spring semester a course in seismic work with complete up-to-date reflection seismic equipment which was in successful operation during the past summer.

KENNETH S. FERGUSON, geologist with the Shell Petroleum Corporation, has been transferred from Alice, Texas, to 1527 Mackenzie Street, San Angelo, Texas.

W. A. MACFADYEN, formerly of Folkestone, England, is now with the Ministry of Economics and Communications, Baghdad, Iraq.

M. A. HARRELL has been appointed an assistant geologist in the United States Geological Survey under the Federal Emergency Administration of Public Works and has been assigned to ground-water investigations in northeastern Arizona. His address is Box 66, Winslow, Arizona.

A. ALLEN WEYMOUTH has changed his address from Box 750, Coalinga, California, to the Bahrein Petroleum Company, Ltd., Bahrein Island, Persian Gulf.

W. E. WRATHER, geologist of Dallas, Texas, and president of the Texas Historical Society, addressed the Texas Geographic Society, at Dallas, on November 10. He illustrated his talk on "An Eight Thousand-Mile Journey Through Africa" with motion pictures.

HARRISON W. ROSE, formerly of 216 Stratford, Houston, Texas, is now with the Sun Oil Company, at Beaumont, Texas.

WILLIAM W. CLAWSON, recently with the Indian Territory Illuminating Oil Company at Oklahoma City, is now on the geological staff of the Magnolia Oil Company at Dallas, Texas. His home address is 3115 Mockingbird Lane.

The first series of the U. S. GRANT memorial lectures at Northwestern University, Evanston, Illinois, was given by W. H. COLLINS, director of the Geological Survey of Canada, on November 21, 22, and 23. The subjects were "The Economic Future of Northern Canada," "Major Correlational Problems of the Great Lakes Region," and "The Sudbury Mining Field."

L. L. FOLEY, of the Mid-Kansas Oil and Gas Company, Tulsa, talked on "Curves and Co-ordinates for Engineers"; and JOHN M. ALDEN, of the United States Geological Survey, Tulsa, talked on "Functions of the United States Geological Survey" before the Mid-Continent Section of the Petroleum Division of the American Mining and Metallurgical Institute at Tulsa, November 13.

At its meeting on November 23, the Geological Society of Chicago was addressed by W. H. COLLINS, director of the Canadian Geological Survey, on the subject "The Behavior of Some Basic Magmas."

GEORGE C. MARTIN, consulting geologist, formerly paleontologist and geologist on the United States Geological Survey, has moved from Washington, D. C., to 503 North Thirteenth Street, Corvallis, Oregon. On the invitation of Dean E. L. PACKARD, Mr. Martin has been granted use of the facilities of the department of geology at Oregon State College and will do his scientific work and writing there.

EPHRAIM NOBLE LOWE, director of the Mississippi Geological Survey, University, Mississippi, died last September at the age of 69 years. He was appointed assistant state geologist in 1908 and became director in 1909.

A. W. GILES, professor of geology at the University of Arkansas, Fayetteville, presented a paper on "The Boone Chert" before the Tulsa Geological Society, November 20.

ELLIOTT SWEET talked on "The Limitations of the Seismic Method" before the Oklahoma City Geological Society, November 13.

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